



GEOREFS No:  
31G-224

FOUNDATION INVESTIGATION  
AND DESIGN REPORT FOR  
PROPOSED BARNES CREEK CULVERT  
HIGHWAY 416  
SOUTH OF KEMPTVILLE  
W.P. 161-96-00, DISTRICT 9

Submitted to:

**Ministry of Transportation**  
355 Counter Street, Postal Bag 4000  
Kingston, Ontario K7L 5A3  
Canada

Submitted by:

AMEC Earth & Environmental Limited  
104 Crockford Boulevard  
Scarborough, Ontario, M1R 3C6  
Canada

27 November 2001

TT21836

27 November 2001

**Reference Number: TT21836**

Ministry of Transportation  
355 Counter Street, Postal Bag 4000  
Kingston, Ontario K7L 5A3  
Canada

**Attention: Mr. Ted Phillips, C.E.T, Ltd. Lic.  
Project Soils Eng. Officer  
Geotechnical Section**

Dear Sir:

**Re: FINAL FOUNDATION INVESTIGATION AND DESIGN REPORT  
PROPOSED BARNES CREEK CULVERT  
HIGHWAY 416, SOUTH OF KEMPTVILLE  
W.P. 161-96-00, DISTRICT 9**

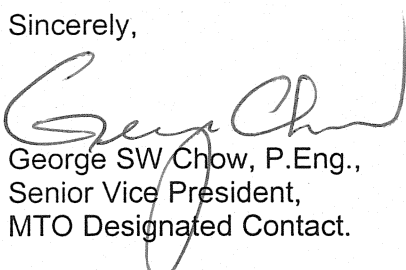
We take pleasure in enclosing three copies of our Final Foundation Investigation and Design Report carried out for the above mentioned project and we will be glad to discuss any questions arising from this work.

This report was finalized based on the comments received from MTO Foundations and Structural Sections.

Soil samples will be retained for a period of one year, and will thereafter be disposed of unless we are otherwise instructed.

We thank you for giving us this opportunity to be of service to you.

Sincerely,



George SW Chow, P.Eng.,  
Senior Vice President,  
MTO Designated Contact.

GSWC/rm

Encl.: Report No. TT21836 (Final Investigation and Design Report)

Cc: 1 – copy to:  
Ontario Ministry of Transportation  
Pavements and Foundations Section  
Foundations Group  
Room 223, Central Building  
1201 Wilson Avenue  
Downsview, Ontario, M3M 1J8

Attn: Mr. Tony Sangiuliano, P. Eng.

AMEC Earth and Environmental Limited  
104 Crockford Boulevard  
Scarborough, Ontario  
Canada, M1R 3C1  
Tel +1 (416) 751-6565  
Fax +1 (416) 751-7592  
www.amec.com

Ontario Ministry of Transportation  
Proposed Barnes Creek Culvert  
Highway 416, South of Kemptville  
WP. 161-96-00, District 9, Kemptville  
Foundation Investigation and Design Report  
Reference Number: TT21836  
27 November 2001  
page (i)

## TABLE OF CONTENTS

|            |   |           |
|------------|---|-----------|
| <b>1.0</b> | <b>INTRODUCTION .....</b>   | <b>1</b>  |
| <b>2.0</b> | <b>SITE DESCRIPTION AND HISTORY .....</b>   | <b>1</b>  |
| <b>3.0</b> | <b>PHYSIOGRAPHY .....</b>   | <b>2</b>  |
| <b>4.0</b> | <b>INVESTIGATION PROCEDURES .....</b>   | <b>2</b>  |
| <b>5.0</b> | <b>SUB-SURFACE CONDITIONS .....</b>   | <b>4</b>  |
| 5.1        | Fill .....  | 4         |
| 5.2        | Topsoil .....   | 5         |
| 5.3        | Sand and Silt .....   | 5         |
| 5.4        | Silty Clay to Clay .....  | 5         |
| 5.5        | Gravel, Sandy Gravel to Gravelly Sand .....                                       | 7         |
| 5.6        | Inferred Bedrock .....  | 7         |
| 5.7        | Groundwater Conditions .....  | 7         |
| <b>6.0</b> | <b>DISCUSSION AND RECOMMENDATIONS .....</b>                                       | <b>8</b>  |
| 6.1        | General .....   | 8         |
| 6.2        | Background Information .....  | 9         |
| 6.3        | Proposed Options of Construction Methods .....                                    | 9         |
| 6.3.1      | Option 1-Jack and Bore/Auger Boring .....   | 10        |
| 6.3.1.1    | Tunnelling Ground Classification .....  | 11        |
| 6.3.1.2    | Design and Procedures .....   | 12        |
| 6.3.2      | Option 2-Pipe Jacking with TBM .....  | 13        |
| 6.3.3      | Option 3-Micro-Tunnelling .....   | 14        |
| 6.3.4      | Option 4-Utility Tunnelling with TBM .....  | 15        |
| 6.3.5      | Option 5-Ground Improvement using Grouting<br>and Tunnelling by Hand Mining ..... | 15        |
| 6.3.6      | Option 6-Open Excavation with Shoring .....                                       | 17        |
| 6.4        | Recommended Options .....   | 18        |
| 6.5        | Settlements .....   | 18        |
| 6.6        | Tunnel Shaft .....  | 19        |
| 6.7        | Construction Consideration .....  | 20        |
| 6.8        | Instrumentation and Monitoring .....  | 21        |
| 6.9        | Soil Disposal .....   | 21        |
| <b>7.0</b> | <b>CLOSURE .....</b>  | <b>21</b> |

Ontario Ministry of Transportation  
Proposed Barnes Creek Culvert  
Highway 416, South of Kemptville  
WP. 161-96-00, District 9, Kemptville  
Foundation Investigation and Design Report  
Reference Number: TT21836  
27 November 2001  
page (ii)

## **TABLES**

|         |   |
|---------|---|
| Table 1 | Summary of Grain Size Distribution Tests Results                  |
| Table 2 | Summary of Atterberg Limits Tests Results                         |
| Table 3 | Index Properties of Oedometer Test Samples                        |
| Table 4 | Summary of Undrained Shear Strength of the Clay                   |
| Table 5 | Summary of Construction Methods                                   |
| Table 6 | Tunnelman's Ground Classification and Probable Working Conditions |

## **FIGURES**

|                           |                                |
|---------------------------|--------------------------------|
| Figure No. 1              | Key Map                        |
| Figure Nos. 2 to 10       | Grain Size Distribution Curves |
| Figure Nos. 11, 12 and 13 | Plasticity Charts              |
| Figure Nos. 14 to 19      | Consolidation Tests Results    |

## **RECORD OF BOREHOLE SHEETS**

Notes to Borehole Logs  
Boreholes 1, 2, 3 and 4

## **DRAWING**

Drawing No. 1: Borehole Location and Soil Strata

## **1.0 INTRODUCTION**

AMEC Earth & Environmental Limited (formerly AGRA Earth & Environmental Limited), Consulting Geotechnical, Materials Quality Control and Environmental Engineers, has been retained by Ontario Ministry of Transportation (MTO) to conduct a foundation investigation for proposed replacement of the Barnes Creek Culvert under the existing Highway 416 embankment, near Kemptville, Ontario. The proposed culvert is to be located either to the north or south of the existing culvert at a distance of approximately 5 m from the existing culvert alignment. The proposed work is under W.P. 161-96-00, District 9, in the Township of North Grenville (Geographic Township of Oxford-On-Rideau). The site location is as shown on the Key Map on Figure No. 1.

The purpose of this investigation is to determine the sub-surface conditions at the site of the proposed culvert by means of a number of exploratory boreholes, in-situ tests and laboratory tests on selected samples. Based on our interpretation of the data obtained, recommendations are provided on the geotechnical aspects of the design of the new culvert. Comments are also provided on anticipated construction issues where they may affect the geotechnical design of the proposed culvert.

The plan and cross-section drawings for the existing culvert were provided to us by Ontario Ministry of Transportation, as shown on Drawing No. 1.

This report summarizes the results of this geotechnical investigation.

## **2.0 SITE DESCRIPTION AND HISTORY**

The site is located about 3.0 km south of Kemptville on Highway 416, approximately 130 m north of the Canadian Pacific Railway (CPR) right of way. The existing culvert under the northbound lanes (NBL) of Highway 416 consists of a 2.0 m diameter corrugated steel pipe (CSP) of about 60 m in length underneath an about 10 to 11 m high embankment. It is understood that the NBL embankment and the CSP culvert was built in the 1970's during the construction of Highway 416 (formerly Highway 16) Overpass structure over the CPR. The existing culvert under the southbound lanes (SBL) of Highway 416, on the other hand, consists of a 2.4 m wide and 1.2 m high (opening) concrete box culvert underneath the 11 m high embankment. This concrete culvert is an extension of the CSP culvert and it was constructed in 1998 during the twinning of Highway 416. The existing embankment is slightly higher along the SBL than the NBL with the existing ground surface of SBL left shoulder at El. 107.0 m while the NBL right shoulder at El. 106.4 m. The median of Highway 416 is depressed with ground level of approximately 5 m below the existing road grades. Embankment side slopes are in the order of 2 horizontal to 1 vertical.

.../...

The Barnes Creek flows through the culvert in a westerly direction: from the farmer's field in the east towards west underneath the embankment and then towards north parallel to the toe of the embankment. The water in the creek was about 0.3 m deep at the time of the investigation. Invert elevation of the existing culvert is at El. 94.7 m on the east end and at El. 94.4 m on the west end of the culvert. The surrounding area on the west side of the embankment is generally wooded with trees and bushes beyond the creek; while on the east side up to the property line (right of way limit), there is a ditch, dirt road and tree line to the north of the existing culvert, and treed area to the south of the culvert. Beyond the east property line is a farmer's field.

### **3.0 PHYSIOGRAPHY**

The proposed culvert is located within the physiographic region of the Ottawa-St. Lawrence lowlands. During the last glaciation, a glacial till plain was deposited in the area. The till plain consists of oval hills of glacial till with smooth convex contours (drumlinized).

After the glaciation period the Champlain Sea inundated the Ottawa-St. Lawrence lowlands depositing marine silts and clays and reworking or eroding the existing till.

Based on available geologic information, bedrock in the investigated area is composed of a grey dolostone which belongs to the Oxford Formation of the Beekmantown Group of Lower Ordovician Period.

### **4.0 INVESTIGATION PROCEDURES**

The fieldwork for the investigation was carried out during the period between 26 July 2001 and 30 July 2001, and consisted of drilling and sampling 4 boreholes (Boreholes 1 to 4, inclusive) to depths of 7.8 m to 19.1 m below the existing ground surface.

The plan locations of the boreholes, and the stratigraphic section are shown on Drawing No. 1. Details of sub-surface conditions encountered at each borehole location, including the results of in-situ testing, are presented on the Record of Borehole sheets.

Boreholes 1, 3, and 4 were advanced, using hollow stem continuous flight augers, with a track-mounted power auger drill rig (FN 240 Nodwell) owned and operated by Marathon Drilling Corporation Limited. Borehole 2 was advanced by hand drilling method since this location was not accessible with a drill rig. This operation was also performed by Marathon Drilling under the full-time supervision of experienced geotechnical personnel from AMEC Earth & Environmental Limited.

.../...

Sampling in the boreholes was carried out at regular intervals of depth by the Standard Penetration Test (SPT) method, and Thin-Walled tube (TW) method as specified in American Standards for Testing and Materials (ASTM) Method Number: D-1586, and D-1587, respectively. SPT method consists of freely dropping a 63.5 kg hammer for a vertical distance of 0.76 m to drive a 51 mm (nominal) outside diameter split barrel (split-spoon) sampler into the ground. The number of blows of the hammer to drive the sampler into the relatively undisturbed ground for a vertical distance of 0.30 m is recorded as the Standard Penetration Resistance or the 'N'-values of the soil, and this gives an indication of the consistency or the relative density of the soil deposit. In hand drilling operation (Borehole 2), SPT method is modified by freely dropping a 31.75 kg hammer instead of a 63.5 kg hammer, for a vertical distance of 0.76 m and the rest of the method remains the same as above. The recorded 'N'-values produced by hand drilling are divided by two and then reported in the borehole logs. TW method recovers a relatively undisturbed soil sample by hydraulically pushing an 80 mm (nominal) diameter thin-walled metal tube into the in-situ soil.

In-situ undrained shear strength test was performed at the boreholes at various depths in the native silty clay, where permitted by its consistency, by using an MTO standard size field vane according to ASTM Method Number: D-2573.

In addition to borehole drilling and sampling in Borehole 4, a Dynamic Cone Penetration Test (DCPT) was also performed. The test was carried out at about 1.0 m from the borehole location. This test consists of continuously driving a 60° point, 50 mm diameter cone attached to the drill rod, into the undisturbed ground with a driving energy of 475 kJ (63.5 kg hammer free falling for a distance of 0.76 m) per blow. The number of blows for each 0.3 m of penetration is recorded, providing an indication of the relative changes in the soil density with depth.

The soil samples were transported to our Advanced Soil Laboratory in Toronto (Scarborough) for further examination and classification. A laboratory testing programme, consisting of natural moisture content determinations, grain size analyses, Atterberg limits, unit weight, unconfined compression, and one dimensional consolidation tests were performed on selected representative soil samples. The results of the laboratory tests are presented on the appropriate Record of Borehole Sheets and also on Figure Nos. 2 to 19, inclusive. These results are also summarized in Table Nos. 1, 2, 3 and 4.

Groundwater conditions in the open boreholes were observed throughout and after the drilling operations. Standpipe piezometers were installed in Boreholes 2, and 4, to permit long term monitoring of groundwater levels at the site. Boreholes 1, and 3, were grouted on completion.

The borehole locations were initially established and staked out in the field by our field personnel using the existing culvert and road as references. AMEC has retained Annis O'sullivan Vollebakk Surveying Limited to survey the borehole locations in terms of northing and .../...

easting co-ordinates, and geodetic elevations. The locations and co-ordinates of the boreholes are shown on Drawing No. 1; the co-ordinates and elevations are also indicated on the Record of Borehole Sheets.

## 5.0 SUB-SURFACE CONDITIONS

The sub-surface conditions were explored at 4 boreholes locations (Boreholes 1 through 4) during this investigation. The plan location of the boreholes and the stratigraphic section at the borehole locations near the anticipated culvert alignment are shown on Drawing No. 1. Details of sub-surface conditions encountered at each borehole location including the results of in-situ testing, groundwater observations and laboratory test results are presented on the Record of Borehole Sheets. The sub-surface conditions are summarized in the following sections.

In general, the sub-surface stratigraphy comprises embankment fill consisting of sand to sand and gravel with occasional cobbles overlying a topsoil layer and surficial sand and silt layers, which is in turn underlain by predominantly stiff to very stiff silty clay to clay. Bedrock was inferred by auger refusal between Elevations 87 and 89 m, or approximately 8 m below the existing ground surface at the bottom of the embankment. Difficult augering and spoon sampler bouncing were observed during borehole drilling indicating the presence of cobbles and possibly boulders in the embankment fill. It should be noted that cobbles and boulders greater than 35 mm could not be sampled with the spoon sampler.

### 5.1 Fill

Boreholes 1 and 3 were drilled from the shoulder of the embankment of Highway 416, and encountered pavement granular fill to a depth of about 1.1 m.

Below this pavement fill, Borehole 1 on the SBL embankment generally contacted sandy silt to silty sand fill with some gravel extending to a depth of 11.4 m. Grain size distribution tests were conducted on samples from the sandy fill and the results are shown on Figure Nos. 2 and 4. The sandy fill contains occasional cobbles between depths of 2 and 10 m below the existing road grade. A silty clay fill layer was also encountered interlayered within the sandy fill at depths between 9.7 and 10.6 m below the existing road grade. In addition, the bottom portion of the fill contains some clay and the gradation curve of this fill layer is shown in Figure No. 4. Measured 'N' values in the fill generally ranged from 40 to greater than 50 blows/0.3 m indicating compacted embankment fill.

Underneath the pavement granular fill, Borehole 3 on the NBL embankment encountered a generally sand to sandy gravel fill (with a 0.2 m thick silty clay layer at a depth of 3.2 m) extending to a depth of about 10.6 m. Gradation curves of the fill from different levels are .../...

presented on Figure Nos. 3 and 5. This granular fill contains occasional cobbles between depths of 2 and 3 m and between depths of 7 and 10.5 m below the existing road grade. Measured 'N' values in the fill ranged from 28 to greater than 50 blows/0.3 m indicating that the fill was compacted.

At Boreholes 2 and 4 at the bottom of the embankment, below the topsoil, an about 0.5 m thick sand / silty sand fill was also contacted. Grain size curves of these materials are shown in Figure No. 3.

Uniformity Coefficient,  $C_u$ , of the fill materials are determined by the relationship  $D_{60} / D_{10}$ , where  $D_{60}$  is the particle size corresponding to 60% passing on the grain size curve, while  $D_{10}$  is the particle size corresponding to 10% passing on the same curve. Uniformity values are presented on Table 1 in the Appendix. In general, the uniformity of the sand fill ranges between 4 and 375.

## 5.2 Topsoil

Boreholes 2 and 4 were drilled near the ends of the existing culverts at the bottom of the embankment and these encountered 0.1 to 0.2 m thick surficial topsoil layer.

Below the embankment fill, Boreholes 1 and 3 also contacted a topsoil layer, ranging in thickness from about 0.2 to 0.4 m.

It should be noted that the thickness of topsoil and fill may vary in between and beyond the borehole locations.

## 5.3 Sand and Silt

Below the surficial topsoil, a generally cohesionless silt and sand layers, ranging in thickness between 0.3 and 0.5 m, were encountered in Boreholes 1 and 3. Grain size analyses were performed on samples from these layers and the results are shown in Figure Nos. 6 and 7.

Measured 'N'-values within these layers ranged from 14 to 38 blows/0.3 m, indicating a compact to dense relative density. These layers are wet with measured moisture contents ranging from about 13% to 26%.

## 5.4 Silty Clay to Clay

Below the surficial sandy fill in Boreholes 2 and 4, and sand and silt layers in Boreholes 1 and 3, a predominant silty clay to clay deposit was encountered in all the boreholes extending to depths of about 17.5 to 18.7 in Boreholes 1 and 3, and 7.6 to 7.2 m in Boreholes 2 and 4, .../...

respectively. The silty clay to clay deposit has a "blocky" structure indicating that the deposit is somewhat sensitive. Occasional silt seams, traces of gravel and shell fragments were present within this deposit at various depths as shown in the Record of Borehole Sheets. Grain size distribution analyses were performed on samples from this deposit and the results are shown in Figure Nos. 8 and 9.

The Atterberg Limits test results performed on the silty clay to clay samples are also presented in the Plasticity Charts in Figure Nos. 12 and 13 and can be summarized as follows:

|                                    |           |
|------------------------------------|-----------|
| Liquid Limit:                      | 36 to 66% |
| Plastic Limit:                     | 18 to 24% |
| Plasticity Index:                  | 18 to 42% |
| Measured Natural Moisture Content: | 24 to 32% |

The above results indicate that the clay to silty clay deposit has generally medium to high plasticity and is overconsolidated. The clayey deposit is also considered practically impervious with coefficient of permeability,  $k$ , in the order of  $10^{-7}$  to  $10^{-8}$  cm/sec.

In Borehole 4, a less plastic clayey silt layer was encountered at greater depth of about 4.5 m below existing grade. The Atterberg Limits test results performed on the clayey silt samples are also presented in the Plasticity Charts in Figure No. 11 and can be summarized as follows:

|                                    |           |
|------------------------------------|-----------|
| Liquid Limit:                      | 23 to 33% |
| Plastic Limit:                     | 14 to 17% |
| Plasticity Index:                  | 9 to 16%  |
| Measured Natural Moisture Content: | 25 to 32% |

The above results indicate clays of low plasticity.

The Liquidity Index of the clayey deposit was also determined and, as presented in Table 2, the liquidity index is typically in the order of 0.3.

Consolidation tests were also conducted on three relatively undisturbed thin walled samples (TW) of the clays and the results are shown in Figure Nos. 14 to 19, inclusive. Strain energy / work method was used to assess the pre-consolidation pressure of each sample tested. From these results the clayey deposit is considered overconsolidated with estimated pre-consolidation pressure,  $\sigma_p'$ , of between 280 and 520 kPa under the existing embankment, and about 350 kPa outside of the embankment on the east side of Highway 416. The associated over-consolidation ratio (OCR) is in the range of 1.2 to 4.4.

Moisture contents, Atterberg Limits, unit weight, unconfined compression, and consolidation  
.../...

tests were also conducted on samples of the silty clay and the results with depth are presented on the Record of Borehole Sheets and in Tables 1, 2, 3 and 4.

Measured 'N'-values within the silty clay to clay deposit generally ranged from 7 to 29 blows /0.3 m. The low 'N'-value (e.g. N=1) measured near the bottom of this deposit in Borehole 1 may be attributed to soil disturbance due to hydrostatic uplift in the more silty zones of the silty clay.

Undrained shear strengths of the clay to silty clay deposit was measured in-situ by vane test and in the laboratory by unconfined compression test and the results are shown in Table 4. Typical values range approximately between 75 and 130 kPa.

From the results of the investigation, the silty clay deposit has a generally stiff to very stiff consistency.

## **5.5 Gravel, Sandy Gravel to Gravelly Sand**

Below the silty clay to clay deposit, a layer of gravel, sandy gravel to gravelly sand was encountered in all the boreholes. This layer was approximately 0.2 to 1.2 m thick and overlies the probable bedrock which was encountered by auger or sampler refusal in the boreholes. Measured 'N'-values in this gravelly layer ranged from 15 to 53 blows/0.3 m, indicating a compact to very dense relative density.

## **5.6 Inferred Bedrock**

Bedrock was inferred in the boreholes by auger refusal which was encountered between Elevations 87 and 89 m, or approximately 8 m below existing grade at the toe of the embankment. The bedrock in this area consists of dolostone of the Oxford Formation of the Beekmantown Group.

## **5.7 Groundwater Conditions**

Groundwater levels in the open boreholes were observed during drilling and upon completion of each borehole. To permit long term monitoring of groundwater levels at the site, standpipe piezometers were installed in Boreholes 2 and 4. The observed groundwater level was at Elevation 94.5 m, or about the invert level of the existing culvert, at the time of the investigation.

It should, however, be pointed out that the groundwater at the site would fluctuate seasonally and can be expected to be somewhat higher during the spring months and in response to major weather events.

.../...

## **6.0 DISCUSSION AND RECOMMENDATIONS**

This section of the report provides our interpretation of the factual geotechnical data obtained during the investigation. Recommendations on geotechnical aspects of the design are made based on these interpretations. These recommendations are intended for use by the design engineer. Where comments are made on construction, they are provided only to highlight aspects of the construction that could affect design of the project. Those requiring information for construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction method and scheduling.

### **6.1 General**

It should be noted that the subsoil conditions have been determined at widely spaced borehole locations along the proposed approximate culvert alignment. The report is intended to provide a general assessment of the conditions which may be expected along the proposed alignment. The current subsurface conditions may not be sufficient for construction and additional borings may be required to further delineate subsurface conditions for contractual or construction purposes. The comments contained in this report relate to the conditions encountered at the borehole locations only and apply for the specific road embankment crossing. Conditions could vary between and beyond the borehole locations and the design and construction must allow for reasonable variations. Although boulders were not encountered at the borehole locations, the embankment fill would also contain boulders and cobbles. Consequently, there should be provision in the contract for handling them, if encountered.

The two boreholes drilled on top of the embankment were grouted to the ground surface at completion, while the other two boreholes at the bottom were backfilled to the ground surface after completion of the drilling and installation of the piezometers. Any contractor undertaking the works should accurately locate the boreholes and piezometers in the field in relation to the proposed culvert alignment and satisfy himself that the locations of the boreholes will not affect the culvert installation for his method of construction.

Care should be taken to avoid damage to the existing culverts and the existing services (if any), and to minimize settlement. Precaution, as necessary, should also be taken with the use of construction equipment to avoid any damage, road surface subsidence or overloading of the existing embankment.

The professional services of AMEC retained for this project include only the geotechnical aspects of the subsurface conditions and design for the proposed culvert. Other design, construction and environmental assessment work are outside the present scope of services.

.../...

## 6.2 Background Information

As mentioned in Section 2.0 of the report, the existing culvert under the NBL of Highway 416 consists of a 2.0 m diameter CSP of about 60 m in length underneath an about 10 to 11 m high embankment; while the existing culvert under the SBL of Highway 416 consists of a 2.4 m wide and 1.2 m high concrete box culvert underneath an 11 m high embankment. The concrete culvert is an extension of the CSP culvert and was constructed in 1998 during the twinning of Highway 416. Invert elevations of the ends of the existing culverts were measured and were found to be at El. 94.7 m on the east end and at El. 94.4 m on the west end of the culvert.

The proposed culvert will be located either to the north or south of the existing culvert. The anticipated length of the proposed culvert is approximately 105 m and the invert is expected to match the existing one. Final details of the proposed culvert(s) are not available at the time of preparing this report. We understand, however, that a single culvert, up to about 2.5 m in diameter is being considered.

## 6.3 Proposed Options of Construction Methods

Boreholes 1 and 3, which were drilled on top of the existing 10 to 11 m high embankment, and Boreholes 2 and 4, which were put down at the bottom of the embankment beside the culvert ends, showed that the anticipated subsurface condition along the approximate alignment of the new culvert (assuming 2.5 m diameter tunnel) consists of the following mixed face condition (from top to bottom of the tunnel face):

About 1.0 m of sand and gravel fill with occasional cobbles  
and possible boulders, and with clayey and silty zones on the  
west side of the embankment (well compacted, generally damp),  
over

Approximately 0.7 m thick layers of topsoil, sand and silt  
(generally compact, bottom 0.35 m is wet)  
over

About 0.8 m of silty clay to clay (generally stiff, moist)

Above these soil deposits, the boreholes encountered a generally well compacted sand and silt (embankment) fill with occasional cobbles and clayey zones or layers. Boulders were not encountered in the boreholes but may be present in the fill. Below the anticipated soil layers expected to be encountered in the tunnel face, is an extensive stiff to very stiff silty clay to clay deposit.

Groundwater level in the piezometers at Boreholes 2 and 4 was found to be at Elevation 94.5 m,  
.../...

or at about the invert of the existing culvert. Perched water condition could, however, occur due to the accumulation of water within the sand and silt layers (and possibly sand and gravel fill layer) over the practically impervious clay deposit.

Based on the results of the investigation, a number of design options in constructing the proposed culvert(s) were considered at this site. The following six options, which are considered to be feasible for this site, are listed below:

- Option 1: Jack and Bore / Auger Boring
- Option 2: Pipe Jacking with TBM
- Option 3: Micro-Tunnelling
- Option 4: Utility Tunnelling with TBM
- Option 5: Ground Improvement using Grouting and Tunnelling by Hand Mining
- Option 6: Open Excavation with Shoring

The above proposed design options are feasible for construction in terms of geotechnical engineering. The selection of a preferred option will primarily depend on the construction cost, risk of ground subsidence, schedule factors, hydrogeological, environmental and fisheries requirements. Economic and schedule factors which would influence choice of methods include availability of suitable machines, lead time for ordering new machines, and the perceived risk of overrunning the allowed construction budget and period in the event of encountering adverse conditions. In such varied conditions, there is no single 'correct' tunneling method but rather there may be a suite of possible methods to provide a cost effective solution.

The following sections present a discussion of the suitability of six construction methods. Summary of the construction methods are presented in Table 5. Details of each proposed design option are discussed below.

### **6.3.1 Option 1 – Jack and Bore / Auger Boring**

This technique forms a bore hole from a drive shaft to a reception shaft by means of rotating cutting head. Spoil is transported back to the drive shaft by helical auger flights rotating inside a steel casing. The casing is jacked in place simultaneously with the augering operation. After the installation of the steel casing, a reinforced concrete pipe will be installed inside the casing and the gap between the casing and the pipe will be grouted.

The maximum casing diameter used in this operation is limited to about 1.3 m (outside diameter) for most contractors in Ontario. The maximum finished diameter may be in the order of 500 mm to 700 mm (inside diameter). With this information and the proposed invert elevation of about 94.5 m, the anticipated subsurface condition at the tunnel face is a mixed face

.../...

condition as described in Section 6.3 above, except that the sand and gravel fill layer with occasional cobbles near the crown of the tunnel will be thinner and is expected to be in the order of 0.1 m in thickness. It is possible that this layer may be missed during the tunnelling operation.

### 6.3.1.1 Tunnelling Ground Classification

Tunnelling procedures depend upon a number of factors, the most important of which are the groundwater conditions and the soil type through which the tunnel must pass. Table 6 presents the classification of the ground according to terminology used by tunnel laborers (commonly known as the Tunnelman's Ground Classification System), the soil types and the probable tunnel working condition for each classification.

According to the Tunnelman's Ground Classification System, the compacted sand and gravel fill layer encountered on the east side of the embankment is classified as 'slow raveling' if damp but could be 'fast raveling' when wet. The likelihood of fast raveling is considered low during low groundwater level conditions (e.g., summer) but could be high during high groundwater level conditions such as during snow melt, after heavy rainfall and Spring. Based on the test results, the uniformity coefficient of the embankment fill varies from 23 to 375 indicating that the fill is relatively 'well graded'. The fines content in the fill at and above the tunnel crown ranges between 8 and 75 % indicating a generally silty material. The underlying topsoil, sand and silt layers above the water table is also considered 'slow raveling'. Below the water table these layers are considered 'flowing' to 'fast raveling'. The generally stiff clay deposit at the bottom section of the tunnel face is classified as 'firm' and possibly 'swelling' ground.

In raveling ground, the material above the tunnel or in the upper portion of the tunnel working face may sooner or later tend to flake off and fall into the heading. In fast raveling ground, the process starts within a few minutes; otherwise, it is described as slow raveling. The action is progressive and may lead to open cavities above the tunnel or even lead to sinkholes at the surface. The raveling can be prevented if at least moderate support (or temporary support) is provided at an early stage before the loosening becomes extensive. Alternatively, raveling ground can be modified by drainage, grouting, or freezing.

Flowing ground condition is often caused by seepage pressures at the heading. For sands below the water table, available data and experience suggests the material will flow into the tunnel if the uniformity coefficient,  $D_{60} / D_{10}$ , is less than 5 and if the fines (particle sizes smaller than 0.075 mm) content is less than 20 %. Based on the results of the investigation, this condition was encountered in Borehole 3/ Sample 11B as indicated in Table I. These types of soils are considered dangerous in tunneling even when closable face shields or tunneling machines are used. Most flowing ground can be transformed into raveling or even firm ground by drainage, air pressure or by grouting. The risk of encountering this condition is medium to .../...

high since the existing pipe invert is just below and within about 0.5 m of this layer.

In firm ground, the materials generally consist of stiff clays or cemented or cohesive granular materials. In this case, a heading may be advanced by about 0.5 m or more without immediate support. Tunnelling in firm ground can be carried out with lower risk of collapse because there is enough time for the installation of temporary support. This condition may be encountered in the stiff to very stiff silty clay to clay at the bottom section of the tunnel.

Swelling ground generally comprises heavily pre-compressed clays with a plasticity index greater than 30 %. From the test results, the clay below the proposed tunnel invert is considered a swelling ground with plasticity index of 31 to 42% (see Figure 13).

#### **6.3.1.2 Design and Procedures**

Jack and bore method of tunneling is generally suitable in majority of conditions presented above, provided that support is installed promptly. This method is commonly used by local contractors and is generally cost-effective. This technique, however, has limitation to the support of the excavation face (open face). Jack and bore operation is not suitable for wet flowing sand condition and fast raveling condition. To utilize this technique, the water in these pervious layers will first have to be removed by adequate groundwater control method. Based on the grain size curves of samples from the sand layer as presented in Figure No. 6, the estimated coefficient of permeability of the sand layer with trace to some silt is in the order of  $3 \times 10^{-3}$  cm/sec. Groundwater control work should be carried out by experienced specialist contractor and the dewatering procedures should be reviewed by the QVE prior to implementation. Dewatering in the vicinity of a creek could also have an impact on fisheries and environment and should be checked prior to its implementation. Flowing condition can also be controlled by pulling back in the casing and compressing a plug of soil in front of the casing to prevent soil from flowing in. This method of tunnelling is also not suitable for soil with large boulders.

The ground surface settlement as a result of the culvert construction depends to a large extent on the workmanship. Based on the currently proposed alignment, existing subsurface information (and considering a well compacted embankment fill) and average workmanship, it is estimated that the maximum road surface settlement would be in the order of 15 to 50 mm. These settlement values, in our opinion, should be acceptable to the Ministry and if necessary, pavement padding could be carried out to correct this subsidence.

It is a normal practice to install the tunnel on a small grade such that any water seepage into the opening is directed away from the tunnel face. Control of alignment and grade of the steel casing is accomplished by the hydraulic jacks in the shaft. The jacking equipment generally has steel guide rails installed to provide proper alignment and grade to the pipe as it is pushed .../...

forward into the tunnel excavation. Problem with alignment could occur when boulders are encountered in upper portion of the tunnel face. In this case, the boulder may have to be hand-mined, but this should be carried out with care to avoid fast raveling condition and ensure that all voids are filled in with grout. Pre-grouting from the tunnel face may be necessary to ensure stability of the sand fill above the tunnel.

In view of the possible presence of boulders in the granular embankment fill, consideration may be given to lowering the vertical alignment of the casing by at least 0.1 m to try to avoid encountering the possible boulders. The bottom of the liner can be re-graded (by placing concrete or rip-rap) to obtain the desired invert and roughness.

For design, the estimated coefficient of friction between the steel casing and the well compacted sand and gravel fill is 0.3; between the steel casing and compact sand and silt layers is 0.25; between the steel casing and clay is 0.25. For design purposes, an average coefficient of friction of 0.3 can be used. The bulk unit weight of the materials above the tunnel crown could be assigned as  $21 \text{ kN/m}^3$ . For the soils surrounding the tunnel, the estimated Soil Modulus,  $E$ , could be in the order of 50 MPa, while the estimated coefficient of lateral earth pressure at rest,  $k_0$ , could be taken as 0.5 for sand and silt soils, and 1.0 for clay.

It should be noted that with the size limitation of this method, depending on the culvert capacity and fish habitat requirements, two or more tunnels, beside and in addition to the existing culvert, may have to be constructed. The new tunnelled culvert should have a horizontal clear distance of at least 3 m from the existing culvert, so as not to impose excessive loading from the jack and bore operation.

### **6.3.2 Option 2 - Pipe Jacking with TBM**

Pipe jacking with TBM installs a prefabricated pipe through the ground from a drive shaft to a reception shaft. The pipe is pushed by jacks located in the drive shaft and the jacking force is transmitted through the pipe to the face of the excavation. The excavation with this method is accomplished by a TBM (Tunnel Boring Machine) and the spoil is transported out of the jacking pipe and shaft manually or mechanically.

Because of the large jacking forces required to push large diameter pipe through the ground, the shaft floor and thrust reaction structure must be designed to withstand the weight of the pipe segments and the jacking forces. Pipe lubrication using bentonite or polymer slurry may be used to reduce skin friction. This lubrication must be pumped continuously in the void between the pipe and the soil while the jacking process is underway.

The anticipated maximum diameter of the tunnel liner on this project is 2.5 m and this can be achieved expeditiously using a TBM. It is also anticipated that the invert of the tunnel liner will slightly be lower than the existing invert (El. 94.5 m) of the culvert, i.e., the liner invert could be

.../...

at about El. 94.2 m. The desired final invert of the pipe could be achieved by the placement of concrete at the pipe bottom. With these pipe diameter and invert elevation, the subsurface condition is expected to be a mixed face as described in Section 6.3, with approximately of 1.0m of sand gravel fill with occasional cobbles and possible boulders, and with clayey and silty zones on the west side of the embankment.

The classification of these soils as per the Tunnelman's Ground Classification System is presented in the previous Section 6.3.1.

This tunneling method is so versatile that it can be executed with any ground condition (except large boulders) with adequate precautions. In unstable soil conditions such as the embankment fill and the underlying wet sand and silt layers, Earth Pressure Balance Machine (EPBM) or slurry shield TBM is required to counterbalance the ground and hydrostatic pressures and to minimize ground subsidence. With EPBM, dewatering of the wet sand and silt is not required, which will not impact on fisheries and the environment.

The main disadvantage of this method is its high capital and set-up costs. This technique also requires good operator skill and experience. In addition, this method has a very tight alignment and grade tolerance since the permanent lining (the pipe segments) is being installed during the tunnel operation. If large boulders are encountered, hand-mining may have to be employed which could lead to project delay and extra costs.

With pipe jacking and the use of EPBM, if operated properly, the maximum ground settlement is expected to be minimal in the order of 10 to 35 mm, which is considered acceptable under the road.

The various soil parameters presented in Section 6.3.1 are also applicable in this method.

The minimum clear distance of this tunnel from the existing culvert should be at least 3 m (preferably 5 m) to avoid damage to the existing culvert.

### **6.3.3 Option 3 - Micro-Tunnelling**

This technique is the improvement of the pipe jacking technique with TBM as described in Section 6.3.2. It is a remotely controlled, guided pipe-jacking process that provides continuous support to the excavation face. The guidance system usually consists of a laser mounted in the drive shaft communicating a reference line to a target mounted inside the tunnelling machine. This technique provides ability to control excavation face stability by applying mechanical or fluid pressure to counterbalance the earth and hydrostatic pressures.

The soil condition and classification are as described in the previous section (Section 6.3.1).

The main advantage of this technique is that it is sophisticated and will most likely complete the project in shorter time. It will also complete the tunneling operation with even less ground subsidence, if operated properly, which is estimated to be about less than 15mm.

.../...

The main disadvantage of this method is its very high cost and that it may not be available locally.

The soil parameters presented above are also applicable with this method.

The minimum clear distance of this tunnel from the existing culvert should be at least 3 m (preferably 5 m) to avoid damage to the existing culvert.

#### **6.3.4 Option 4 - Utility Tunnelling with TBM**

Utility tunneling with TBM is a two-stage process in which a temporary ground support system is constructed to permit the installation of the pipe segment. The temporary tunnel liner is installed as the tunnel is constructed. The temporary ground support system can be steel or concrete segmental liner or steel ribs with wood lagging. Groundwater control is required to minimize water leakage into the tunnel. Workers are required inside the tunnel to perform the excavation and/or spoil removal. The excavation will be accomplished by a TBM.

This method is similar to Option 2 – Pipe Jacking with TBM, except that a temporary support is required.

The main disadvantage of this technique is higher risk of subsidence during the installation of temporary support especially if ribs and lagging is used. Anticipated settlements could be in the order of 20 to 50 mm. Permanent lining will also be required which adds to the cost of construction.

On the other hand, the major advantage of this method is that it can tolerate some misalignment since the product pipe can be grouted inside the liner at the correct grade. The probability of misalignment is greater if the tunnel excavation encounter boulders in the embankment fill.

The minimum clear distance of this tunnel from the existing culvert should be at least 3 m (preferably 5 m) to avoid damage to the existing culvert.

#### **6.3.5 Option 5 - Ground Improvement using Grouting and Tunnelling by Hand Mining**

This technique is similar to Option 4 above except that the unstable soils will be stabilized by grouting prior to the tunnel excavation. The temporary ground support system can be steel or concrete segmental liner or steel ribs with wood lagging. Groundwater control is required to minimize water leakage into the tunnel. Workers are required inside the tunnel to perform the excavation and/or spoil removal. The excavation will be accomplished by hand mining with the assistance of small excavation.

With this method, control of alignment and grade is accomplished by overmining in the direction of the change and the pipe will move into the overmined area as it is pushed forward.

.../...

Permeation grouting (penetration grouting) technique can be used to fill the pore spaces in soil with grout without disturbing the soil formation. Permeation grouting refers to the replacement of air and water in voids between soil particles with a grout fluid at low injection pressure so as to prevent fracturing of the soil mass. Grouting will therefore increase the shear strength of the fill materials and hence reduce settlement and improve tunnel face stability.

Cementitious grout or cement-based grout is most commonly used, cost-effective materials for ground strengthening. The water to solids ratio is the prime determinant of their properties and characteristics including stability, fluidity, strength, and durability. Bentonite, chemical agent, fillers, etc may be added to enhance certain properties of the grout in order to achieve the specific purposes of grouting.

In general, a grouting material should have low viscosity, a controllable setting time, and high strength once it is in the ground. Further, the grout should be non-toxic, permanent, and inexpensive.

The work can be carried out by using drilling and grouting plant and equipment. The drilling and grouting operations will be carried out from inside the tunnel. Boreholes will be drilled at the tunnel face followed by grouting, prior to excavation. The orientation and layout of boreholes will be determined by the specialist tunnelling and grouting contractors. Grouting should be commenced once the borehole is completed. In order to grout a particular depth of the ground, the corresponding depth of borehole is isolated by expanding rubber packers built into the drilling rods. Grout is then only allowed to flow into the soil from between two packers, or if a single packer is used, between the packer and the bottom of the hole.

The grout mix and grouting operations should be designed to avoid ground heaving, damages to the embankments, damages to existing utilities and structures. Any blocked sub-soil drainage system should be replaced immediately.

The grout mix design, grouting operations and selected grouting methods/procedures should be designed and performed by experienced specialist grouting contractor. The grout mix design grouting procedures, plant and equipment to be used should also be reviewed prior to construction works.

The main advantage of this technique is that the unstable soils will be stabilized by grouting, and that large boulders can be removed.

This technique is limited by the difficulty of the control of the penetration (in terms of quantity and direction) of the grouting materials in the fill and the verification and quality control of the work. Further, some underground utilities and sub-soil drainage may be damaged or blocked by the grouting operations. This technique is also limited by its impact to the environment and fisheries. Higher risk of ground subsidence may also be encountered with anticipated settlements could be in the order of 20 to 50 mm. In addition, with this method, the tunnel project will take a longer time to complete.

.../...

The minimum clear distance of this tunnel from the existing culvert should be at least 4 m (preferably 5 m) to avoid damage to the existing culvert.

### 6.3.6 Option 6 - Open Excavation with Shoring

This consists of conventional open cut excavation technique with the ground supported temporarily by sheet piling. This method is limited by the availability of space and requirement of lane closure of Highway 416. We understand that this option may not be a desirable one. However, this method of construction will be briefly discussed below.

For construction staging, it is assumed that one direction of traffic (NBL or SBL) will be shut down at a time, while the other direction is open for traffic.

In this option, the existing embankment fill, which consist primarily of sand and silt fill with some gravel and occasional cobbles, will be excavated to about elevation 94 m (below the invert of the existing culvert) or about 13 m below the road grade, place the bedding and construct the proposed concrete box culvert. Details of the culvert are not available at the time of preparing this report. During construction, however, we understand that the existing culvert will have to be maintained until a new one is constructed. In this case, vertical excavation along the road embankment and temporary shoring will be required. Shoring system could be a combination of sheet piles, caisson wall, or soldier piles and lagging, rakers, struts and soil anchors.

For shoring of the existing embankment fill, the following parameters can be used in the design:

Coefficient of lateral earth pressure:

|                     |      |
|---------------------|------|
| Active ( $k_a$ ) :  | 0.33 |
| At-rest ( $k_o$ ) : | 0.5  |
| Passive ( $k_p$ ) : | 3.0  |

Active earth pressure coefficient can be used provided that small movement of the wall is allowed. For a rigid retaining structure where the active earth pressure condition cannot develop, the coefficient of earth pressure "at-rest" should be assumed for the design. For sloping ground at 2H:1V,  $k_a = 0.54$  and  $k_o = 0.76$  can be used in the design.

|  |                      |
|--|----------------------|
| Bulk unit weight of retained soil ( $\gamma$ ) : | 21 kN/m <sup>3</sup> |
|--|----------------------|

For soil anchors, the following unfactored friction factors between soil and grout are as follows:

|                     |     |
|---------------------|-----|
| Granular Fill:      | 0.4 |
| Silty Clay to Clay: | 0.3 |

For design purposes, the groundwater table can be assumed at Elevation 95.5 m.

.../...

To check the stability of the base against basal heave, the Stability Number,  $N_s = \gamma H / C_u$ , for a braced sheeted excavation, was calculated and this was found to be in the order of 2.2, indicating stable base. Ground movement usually begins when  $N_s = 3$ , and with increasing values of  $N_s$ , heaving of the base and settlements adjacent to the excavation begin to increase rapidly to a considerable distance from the excavation.

For preliminary design, a factored geotechnical resistance at U.L.S of 400 kPa and a geotechnical resistance at S.L.S equal to 200 kPa can be assigned to the founding clay subgrade at approximate Elevation of 94.0 m. The serviceability condition corresponds to total and differential settlements less than 25 and 20 mm, respectively.

Special Provision 902S01 – Excavation and Backfilling- Structures should be included in the Contract Documents. Lower sections of the shoring (e.g., sheet piling) may have to be left in place, if withdrawal of the shoring could cause excessive settlement of the newly constructed culvert, prior to backfilling. Backfilling requirements will be provided when this option is selected as one of the preferred options. In addition, Special Provision 539S01 – Roadway Protection should also be included in the Contract Documents. In this case, it is our opinion that a Level 3 Performance Level with maximum angular distortion of 1:100 but not more than 50 mm lateral movement should be used.

The recommended minimum clear distance of the new culvert from the existing culvert is about 5 m to avoid damage to the existing culvert.

#### **6.4 Recommended Options**

Based on the above discussion of methods of construction of the proposed culvert(s), we recommend the following design options be considered for further evaluation:

1. Option 1 - Jack and Bore / Auger Boring
2. Option 2 - Pipe Jacking with TBM (using EPBM)
3. Option 4 – Utility Tunnelling with TBM

It is noted that, the existing culvert, after it is strengthened and re-lined, could also be re-used. Further, in order to minimize the risk of encountering boulders in the fill, and potential problems during tunnelling, it is recommended that the inverts of the tunnelled pipes be lowered as deep as possible.

#### **6.5 Settlements**

Settlement caused by tunneling in soft ground is the aggregate of two basic types of settlement which consist of ground loss or 'immediate' settlement, and consolidation settlement.

.../...

The 'immediate' settlement is the direct result of the movement of ground into the tunnel heading. The factors which influence the magnitude of immediate settlement due to tunneling include soil strength and stiffness, the method of tunneling and the quality of tunnel operations (including the method of handling localized factors such as encountering boulders). Even when tunnelling is carried out apparently through homogeneous soils with the same equipment and crews, ground settlements typically vary by a factor of 2 or 3. This variation can be ascribed to items such as ploughing of the shield or use of overcutters, quality and speed of ring grouting and localized variations in soil type, strength or stiffness.

Despite the uncertainty, the large quantity of information on case studies available in the literature allows approximate estimates of peak settlements to be made based on typical parameters for various conditions. Generally, estimates of maximum immediate settlements over the tunnel centerline are less than 50 mm. These settlements are likely to be experienced to a horizontal distance on either side of the tunnel equal to about one-half the depth to the tunnel axis. Smaller settlements will likely occur to a horizontal distance equal to about one tunnel axis depth.

Good workmanship and site control is the most effective way to reduce immediate settlements to practical minimum. Factors to consider in the specification and review of tenders include grouting behind the temporary support system as quickly as possible, minimizing the use of overcutters and minimizing overbreak due to excavation of boulders. Full-face machines can roll boulders around the head causing overbreak. Where overbreak occurs due to boulders or overcutting, the voids should be filled as soon as possible. With open shields, and TBMs to a more limited extent, sand bags or gravel packs can be used to fill overbreak. With EPBM or slurry shields, weak grout or slurry can be injected around the skin.

The term 'ground loss' as discussed above does not include loss of ground resulting from face instability. Much greater settlements than the estimates given above are likely to occur where there is instability at the face.

Consolidation settlement is the settlement caused by pore-pressure changes in compressible deposits as related to dissipation of excess pore pressures induced by tunneling and also from long term seepage effects into the tunnel. Because the groundwater level of this site is approximately at the invert of the existing culvert, consolidation settlements are unlikely to be significant. The estimated settlements for the construction options discussed are summarized in Table 5.

## **6.6 Tunnel Shaft**

Where insufficient space exists to permit open excavation, appropriately braced shafts may be .../...

required for methods of construction using horizontal boring technique. The depth of overburden excavation at the shaft locations (at the bottom of the 10 to 11 m high embankment) will range from about 2 to 3 m below existing ground surface. The excavation will be carried out through embankment fill, topsoil, surficial wet sand and silt layers and silty clay to clay deposit, probably extending to about Elevation 94.0 m. Since perched water could be encountered at Elevation 95.5 m, appropriate dewatering control will be required at the shaft excavations. Groundwater seepage into the excavation can be handled by continuous pumping from properly filtered sumps located within the excavation.

The design of the braced excavation/shafts in the overburden should take into account horizontal soil loads, hydrostatic water pressure, and any surcharge due to construction loadings. The shoring system could be designed to resist a constant lateral earth pressure distribution with depth and hydrostatic water pressure, where applicable. A coefficient of lateral earth pressure of 0.3 can be used in the design of temporary shoring and support system.

## **6.7 Construction Consideration**

As mentioned before, in determining the method of construction suitable for this project, consideration should also be given into the different aspects of this project which include hydrogeological, environmental, and fisheries.

During the construction, parking of heavy equipments at the side of the road on top of the embankment should be avoided. In addition, the stability of the existing embankment should be checked taking into account the high surcharge loads. Excavated materials should not be stockpiled on top of the embankment.

Excavation from the tunnel and from the shaft should be stockpiled at the bottom of the embankment, but not adjacent to shaft. The excavated materials are expected to consist of a mixture of embankment fill, topsoil, wet sand and silt, and clay. The excavated material could be temporarily stockpiled not higher than 3 m, with side slopes not steeper than 1.5H to 1V. These materials are not suitable as backfill under the road.

For the protection of the fish habitat and other organisms in the creek, pollution and/or siltation of the creek should be avoided. During the construction, temporary run-off controls such as sediment trap, interceptor drain, dike and/or silt fence should be provided and installed to prevent uncontrolled water flow and sediment down slope towards the creek. Any surplus excavated materials should be removed off-site as soon as possible. Covering the excavated material with tarpaulin could eliminate unwanted surface water run-off, but this may prove impractical especially for large stockpile. In addition, effluent water from any dewatering operation should be contained, and if necessary, this should be tested and treated prior to discharge to open water.

.../...

## 6.8 Instrumentation and Monitoring

It is recommended that instrumentation in the form of settlement monitoring be carried out for the Highway 416 embankment along and in the vicinity of the proposed culvert alignment. The settlement monitoring points will be placed along the tunnel axis and a distance from this axis, on top and slopes of the embankment. In addition to the settlement monitoring, the excavated soil types and quantity should also be determined during the tunneling operation by an experienced geotechnical personnel. The quantity of excavated materials will be compared with the theoretical volume of excavation in order to assess the risk of over-excavation. Such monitoring is necessary to confirm that any settlement/ movement associated with the proposed construction would be within tolerable limits.

## 6.9 Soil Disposal

The excavated materials from the tunnel and shaft construction should be stockpiled and checked for contamination prior to removal/disposal off-site, in order to determine which disposal option is best suited for the excavated materials. If found "clean", these materials can be used to flatten slopes.

## 7.0 CLOSURE

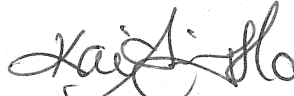
Since all details of the design are not known during the time of the investigation, we recommend that AMEC be retained during the final design stage to verify that the design is consistent with our recommendations, and that assumptions made in our analysis are valid.

Sincerely,

**AMEC Earth and Environmental Limited**

  
Ramon Miranda, P. Eng.  
Head, Transportation Department



  
Kai-Sing Ho, Ph.D., P. Eng.  
Principal  
MTO Designated Consultant



**TABLES**

**TABLE I**  
**Summary of Grain Size Distribution Tests Results**

| BH No. | Sample No. | Depth (m) | Elevation (m) | Gravel % | Sand % | Silt % | Clay % | Uniformity Coeff. $D_{60}/D_{10}$ | Percent Fines (.075mm) | Soil Type         |
|--------|------------|-----------|---------------|----------|--------|--------|--------|-----------------------------------|------------------------|-------------------|
| 1      | 7          | 7.7       | 99.3          | 4        | 22     | 65     | 9      | 23                                | 75                     | Sandy Silt Fill   |
| 1      | 9          | 9.3       | 97.7          | 26       | 35     | 32     | 7      | 375                               | 39                     | Silty Sand Fill   |
| 1      | 11         | 11.0      | 96.0          | 24       | 34     | 30     | 12     | 360                               | 42                     | Silty Sand Fill   |
| 1      | 12B        | 11.7      | 95.3          | 0        | 80     | (20)   |        | N/A                               | 20                     | Sand              |
| 1      | 12C        | 11.9      | 95.1          | 0        | 26     | 61     | 13     | 35                                | 74                     | Silt with Sand    |
| 1      | 13         | 12.4      | 94.6          | 0        | 2      | 37     | 61     | N/A                               | 98                     | Clay              |
| 1      | 14         | 13.2      | 93.8          | 0        | 2      | 34     | 64     | N/A                               | 98                     | Clay              |
| 2      | 1B         | 0.3       | 95.4          | 0        | 78     | (22)   |        | N/A                               | 23                     | Sand Fill         |
| 2      | 2          | 0.9       | 94.8          | 0        | 3      | 51     | 46     | N/A                               | 97                     | Silty Clay        |
| 2      | 4          | 2.2       | 93.5          | 0        | 2      | 40     | 58     | N/A                               | 98                     | Silty Clay        |
| 3      | 6          | 7.1       | 99.3          | 1        | 89     | (10)   |        | 4                                 | 10                     | Sand Fill         |
| 3      | 8          | 8.6       | 97.8          | 48       | 35     | (18)   |        | N/A                               | 18                     | Sandy Gravel Fill |
| 3      | 9          | 9.4       | 97.0          | 65       | 27     | (8)    |        | 335                               | 8                      | Sandy Gravel Fill |
| 3      | 11B        | 11.0      | 95.4          | 0        | 89     | (11)   |        | 3                                 | 12                     | Sand              |
| 3      | 12         | 11.6      | 94.8          | 0        | 2      | 44     | 54     | N/A                               | 98                     | Silty Clay        |
| 3      | 13         | 12.4      | 94.0          | 0        | 2      | 29     | 69     | N/A                               | 98                     | Clay              |
| 4      | 1B         | 0.4       | 95.5          | 0        | 59     | 32     | 9      | 60                                | 41                     | Silty Sand Fill   |
| 4      | 2          | 1.0       | 94.9          | 0        | 2      | 49     | 49     | N/A                               | 98                     | Silty Clay        |
| 4      | 9          | 7.1       | 88.8          | 0        | 2      | 83     | 15     | 12                                | 98                     | Clayey Silt       |

Note: value in ( ) denotes % of silt and clay combined

**TABLE 2**  
**Summary of Atterberg Limits Tests Results**

| BH No. | Sample No. | Depth (m) | Elevation (m) | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) | Natural Moisture Content (%) | Liquidity Index |
|--------|------------|-----------|---------------|------------------|-------------------|----------------------|------------------------------|-----------------|
| 1      | 10         | 10.2      | 96.8          | 40               | 18                | 22                   | 24                           | 0.3             |
| 1      | 13         | 12.4      | 94.6          | 52               | 23                | 29                   | 32                           | 0.3             |
| 1      | 14         | 13.2      | 93.8          | 66               | 24                | 42                   | 38                           | 0.3             |
| 1      | 15         | 13.9      | 93.1          | 53               | 22                | 31                   | 29                           | 0.2             |
| 2      | 2          | 0.9       | 94.8          | 44               | 19                | 25                   | 26                           | 0.3             |
| 2      | 4          | 2.2       | 93.5          | 44               | 22                | 22                   | 31                           | 0.4             |
| 2      | 6          | 3.3       | 92.4          | 43               | 18                | 25                   | 26                           | 0.3             |
| 2      | 8          | 4.5       | 91.2          | 36               | 18                | 18                   | 28                           | 0.6             |
| 3      | 12         | 11.6      | 94.8          | 45               | 20                | 25                   | 29                           | 0.4             |
| 3      | 13         | 12.4      | 94.0          | 60               | 20                | 40                   | 24                           | 0.1             |
| 3      | 14         | 13.9      | 92.5          | 43               | 19                | 24                   | 25                           | 0.25            |
| 4      | 2          | 1.0       | 94.9          | 43               | 20                | 23                   | 28                           | 0.3             |
| 4      | 3          | 1.7       | 94.2          | 52               | 21                | 31                   | 30                           | 0.3             |
| 4      | 4          | 2.5       | 93.4          | 52               | 21                | 31                   | 28                           | 0.2             |
| 4      | 7          | 4.8       | 91.1          | 33               | 17                | 16                   | 25                           | 0.5             |
| 4      | 9          | 7.1       | 88.8          | 23               | 14                | 9                    | 30                           | 1.8             |

**TABLE 3**  
**Index Properties of Oedometer Test Samples**

| <b>Borehole No.</b>                              | <b>1</b> | <b>3</b> | <b>4</b> |
|--|----------|----------|----------|
| <b>Sample No.</b>                                | TW14     | TW13     | TW9      |
| <b>Depth (m)</b>                                 | 13.2     | 12.4     | 7.1      |
| <b>Elevation (m)</b>                             | 93.8     | 94.0     | 88.8     |
| <b>Water Content (%)</b>                         | 38       | 24       | 32       |
| <b>Liquid Limit (%)</b>                          | 66       | 60       | 23       |
| <b>Plasticity Index (%)</b>                      | 42       | 40       | 9        |
| <b>Unit Weight (kN/m<sup>3</sup>)</b>            | 18.3     | 18.6     | 18.5     |
| <b>Initial Void Ratio, e</b>                     | 1.16     | 0.76     | 0.82     |
| <b>Estimated Compression Index</b>               | 0.31     | 0.18     | 0.18     |
| <b>Estimated Preconsolidation Pressure (kPa)</b> | 280      | 520      | 350      |
| <b>In-situ Effective Overburden Stress (kPa)</b> | 240      | 270      | 80       |
| <b>% Sand</b>                                    | 2        | 2        | 2        |
| <b>% Silt</b>                                    | 34       | 29       | 83       |
| <b>% Clay</b>                                    | 64       | 69       | 15       |
| <b>Specific Gravity</b>                          | 2.72     | 2.72     | 2.72     |

**TABLE 4**  
**Measured Undrained Shear Strength**

| BH No. | Sample No. | Depth (m) | Elevation (m) | Field Vane Test (kPa) | Unconfined Compression Test |                    |
|--------|------------|-----------|---------------|-----------------------|-----------------------------|--------------------|
|        |            |           |               |                       | Shear Strength (kPa)        | Failure Strain (%) |
| 1      | 13         | 12.4      | 94.6          |                       | 75                          | 3                  |
| 1      |            | 16.2      | 90.8          | >120                  |                             |                    |
| 2      | 4          | 2.2       | 93.5          |                       | 102                         | 6                  |
| 3      | 12         | 11.6      | 94.8          |                       | 130                         | 5                  |
| 3      |            | 13.2      | 93.2          | >120                  |                             |                    |
| 3      | 16         | 15.5      | 90.9          |                       | 138                         | 4                  |
| 3      |            | 17.6      | 88.8          | >120                  |                             |                    |
| 4      | 2          | 1.0       | 94.9          |                       | 126                         | 7                  |
| 4      |            | 5.3       | 90.6          | >120                  |                             |                    |
| 4      |            | 5.7       | 90.2          | >120                  |                             |                    |
| 4      |            | 7.1       | 88.8          | 42                    |                             |                    |

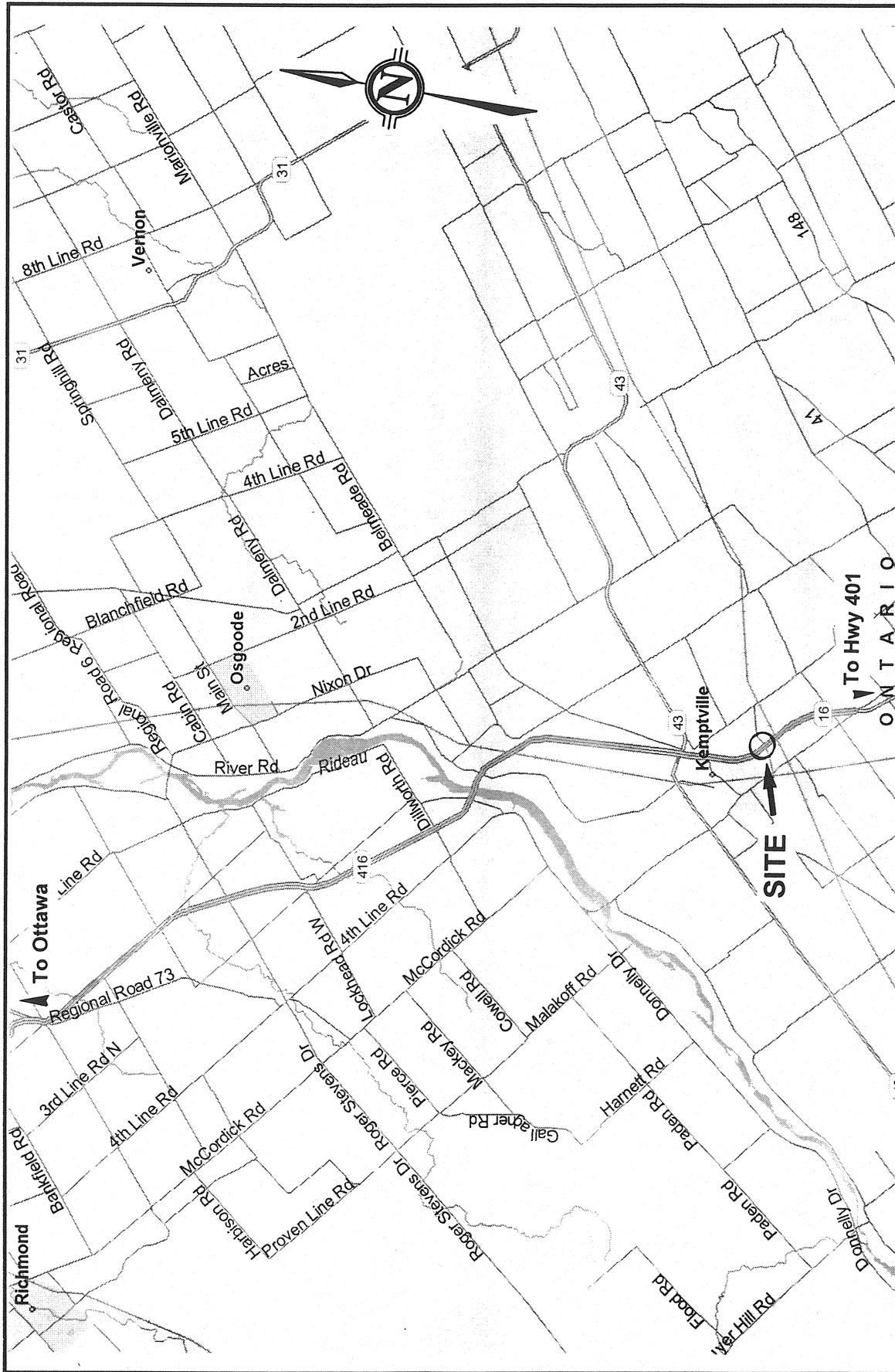
TABLE 5 : SUMMARY OF CONSTRUCTION METHODS

| Option | Construction Method   | Application Range    |                 | Control of Open Face Stability   | Capability of Boulder Excavation  | Temporary Support   | Permanent Lining   | Estimated Settlement (mm) | Alignment Control  | Advantage   | Limitation   | Cost Comparison     |
|--------|---|----------------------|-----------------|--|---|---|--|---------------------------|--|---|--|---------------------|
|        |   | Length (m)           | Diameter (m)    |  |   |   |  |                           |  |   |  |                     |
| 1      | Jack and Bore/<br>Auger Boring                                  | Up to<br>150 m       | 0.2 to<br>1.5 m | Wet/flowing sand condition can be controlled by pulling the augers back in the casing and compressing a plug of soil in front of the casing to prevent soil from flowing in. | Possible to handle small boulders of size up to 25% of the casing diameter. | Provided by the steel casing during the jack and bore operations. | Pipe to be installed inside the steel casing.  | 15 to 50                  | <ul style="list-style-type: none"> <li>By hydraulic jacks in shafts pushing steel casing</li> <li>Not very good control in mixed face</li> </ul> | <ul style="list-style-type: none"> <li>Technique commonly used locally</li> <li>Skill labour, equipment and contractor available locally</li> <li>Relatively lower cost</li> <li>Technique suitable for large variety of soils conditions</li> <li>Minimum ground subsidence if operated properly</li> </ul>  | <ul style="list-style-type: none"> <li>Not suitable in wet runny sand conditions</li> <li>Not suitable for soil with large boulders</li> <li>Maximum pipe diameter limited to 1.3m for most contractors in Ontario</li> </ul>  | Low<br>to<br>Medium |
| 2      | Pipe Jacking<br>with TBM  | Up to<br>400 m       | 1 to<br>3 m     | Earth Pressure Balance Machine or slurry shield TBM is required to maintain face stability.  | Possible to handle small boulders of size up to 25% of the casing diameter. | Not required.   | Pipe installed during the tunnelling operations.   | 10 to 35                  | <ul style="list-style-type: none"> <li>Very tight alignment and grade tolerance</li> <li>Good control</li> </ul>                                 | <ul style="list-style-type: none"> <li>Method can be executed with any ground condition (except large boulders) with adequate precautions</li> <li>Pipe installed during the operations, avoid double handling</li> <li>Minimum ground subsidence if operated properly</li> <li>Low mobilization cost for TBM smaller than 9 ft diameter</li> </ul> | <ul style="list-style-type: none"> <li>High capital cost and setup cost</li> <li>Specialized operation requiring good operator skill and experience</li> <li>Very tight alignment and grade tolerance and expensive corrective actions if mis-aligned</li> <li>TBM over 9ft diameter may not be available locally</li> </ul> | High                |
| 3      | Micro-Tunnelling  | Up to<br>250 m       | 0.2 to<br>3 m   | Micro-Tunnelling Machine is designed to provide ability to maintain face stability.  | Possible to handle small boulders of size up to 25% of the casing diameter. | Not required.   | Pipe installed during the tunnelling operations.   | <15                       | <ul style="list-style-type: none"> <li>Remotely-controlled pipe jacking process</li> <li>Good control</li> </ul>                                 | <ul style="list-style-type: none"> <li>Method can be executed with any ground condition (except large boulders) with adequate precautions</li> <li>Pipe installed during the operations, avoid double handling</li> <li>Minimum ground subsidence if operated properly</li> </ul>   | <ul style="list-style-type: none"> <li>Very high capital cost and setup cost</li> <li>Specialized operation requiring good operator skill and experience</li> <li>Sophisticated equipment</li> <li>Availability of equipment locally</li> </ul>  | Very high           |
| 4      | Utility Tunnelling with TBM                                     | No theoretical limit | 1 to 3 m        | Earth Pressure Balance Machine or slurry shield TBM is required to maintain face stability.  | Possible to handle small boulders of size up to 25% of the casing diameter. | Segmental lining or ribs & lagging with geo-synthetics.           | Permanent lining required to provide long term stability and satisfy hydraulic requirements. | 20 to 50                  | <ul style="list-style-type: none"> <li>Can tolerate some misalignment of casing</li> <li>Relatively good control</li> </ul>                      | <ul style="list-style-type: none"> <li>Method can be executed with any ground condition (except large boulders) with adequate precautions</li> <li>Less sophisticated equipment</li> <li>Low mobilization cost for TBM smaller than 9 ft diameter</li> </ul>  | <ul style="list-style-type: none"> <li>High capital cost and setup cost if TBM over 9ft diameter is used</li> <li>Required temporary support and permanent lining</li> <li>Higher risk of ground subsidence</li> </ul>   | High                |
| 5      | Ground Improvement using Grouting and Tunnelling by Hand Mining | No theoretical limit | 1 to 3m         | Grouting in advance of excavation to minimize water leakage and soil sloughing.  | Good.   | Segmental lining or ribs & lagging with geo-synthetics.           | Permanent lining required to provide long term stability and satisfy hydraulic requirements. | 20 to 50                  | <ul style="list-style-type: none"> <li>Hand-mining and jacking in direction of advance</li> <li>Good control depending on workmanship</li> </ul> | <ul style="list-style-type: none"> <li>Skill labour, equipment and contractor available locally</li> <li>Relatively lower cost</li> <li>Capable to handle large boulder</li> </ul>  | <ul style="list-style-type: none"> <li>Required temporary support and permanent lining</li> <li>Higher risk of ground subsidence</li> <li>Required groundwater control</li> <li>Difficult to control grouting quality</li> </ul>   | Medium              |
| 6      | Open Excavation with Shoring                                    | No theoretical limit | N/A             | Open face supported by temporary shoring such as sheet piles.  | Boulders may affect the sheet pile installation.                            | Temporary shoring by sheetpiling.                                 | Not applicable.  | 25 to 50                  | <ul style="list-style-type: none"> <li>Good control by surveying</li> </ul>  | <ul style="list-style-type: none"> <li>Skill labour, equipment and contractor available locally</li> <li>Lower capital and setup cost</li> </ul>  | <ul style="list-style-type: none"> <li>Required traffic control and lane closure</li> <li>Require groundwater control</li> <li>Large space requirement</li> <li>Boulders in the fill may affect sheetpile installation</li> </ul>  | Very high           |

**TABLE 6**  
**Tunnelman's Ground Classification and Probable Working Conditions**

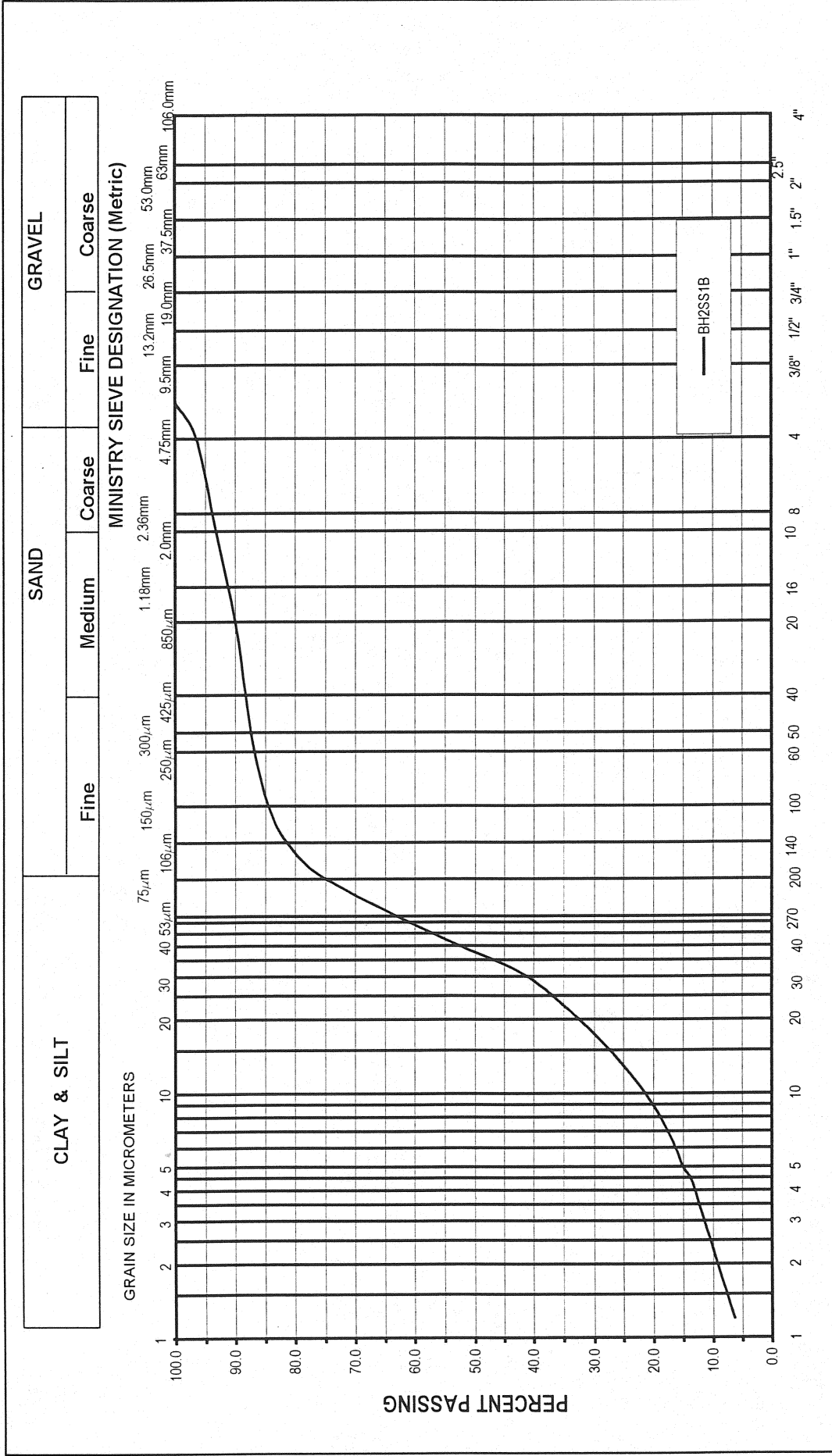
| Soil Classification               | Representative Soil Types  | Tunnel Working Conditions  |
|-----------------------------------|--|--|
| Hard                              | Very hard calcareous clay;<br>Cemented sand and gravel   | Tunnel heading may be advanced without roof support  |
| Firm                              | Loess above GWT; Various calcareous clay with low plasticity   | Tunnel heading may be advanced without roof support. Permanent support can be constructed before the ground will start to move   |
| Slow Ravelling and Fast Ravelling | Fast ravelling occurs in residual soils or in sand with clay binder below the GWT. Above the GWT, the same soils may be <u>Slow Ravelling</u> or even <u>Firm</u>    | Chunks of material may drop out of the crown or the sides some time after the ground has been exposed. In <b>Fast Ravelling</b> ground, the process starts within a few minutes; otherwise, it is classed as <u>Slow Ravelling</u> .   |
| Squeezing                         | Soft or medium-soft clay   | Ground slowly advances into tunnel without fracturing and without perceptible increase of water content in ground surrounding the tunnel.  |
| Swelling                          | Heavily pre-compressed clays with a plasticity index greater than 30. Sedimentary formations containing layers of anhydrite.   | Like squeezing ground, moves slowly into tunnel, but the movement is associated with a very considerable volume increase in the ground surrounding the tunnel.   |
| Cohesive Running And Running      | Occurs in clean, fine moist sand<br><br>Occurs in clean, coarse or medium sand above the GWT   | Removal of the lateral support of any surface rising at an angle of more than about 34° to the horizontal is followed by a "run", whereby the material flows like granulated sugar until the slope angle is approx. 34°. If the "run" is preceded by a brief period of ravelling, the ground is called <u>Cohesive Running</u> . |
| Very Soft Squeezing               | Clays and silts with high plasticity indices   | Ground advances rapidly into the tunnel in a plastic flow  |
| Flowing                           | Any ground below the GWT that has an effective grain size in excess of about 0.005 mm.   | Flowing ground moves like a viscous liquid. It can invade the tunnel not only through the roof and the sides but also through the invert. If the flow is not stopped, it will eventually completely fill the tunnel  |
| Bouldery                          | Boulder glacial till; riprap fill; some land slide deposits, some residual soils. The matrix between boulders may be gravel, sand, silt, clay and in any combination | Problems incurred in advancing shield or in forepoling; blasting or hand mining ahead of machine may become necessary.   |

**FIGURES**



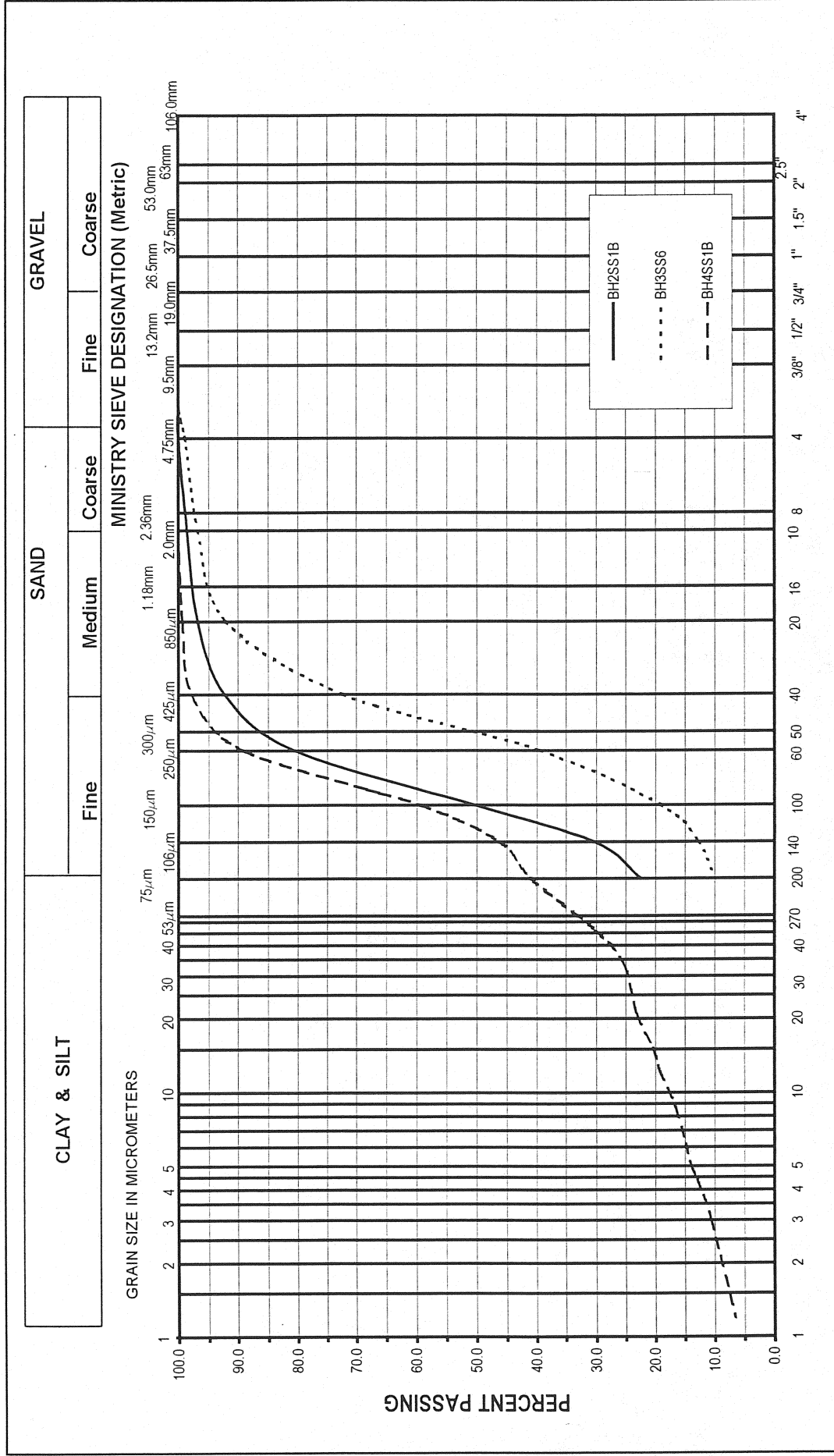
|                                      |                         |
|--------------------------------------|-------------------------|
| AMEC EARTH AND ENVIRONMENTAL LIMITED |                         |
| September 2001                       | Prepared By: PPM        |
| Ref.No. TT21836                      | Reviewed By: RM         |
| KEY MAP                              |                         |
| Barnes Creek Culvert                 |                         |
| W.P. 161-96-00                       | Highway 416, District 9 |
| Figure: 1                            |                         |

# UNIFIED SOIL CLASSIFICATION SYSTEM

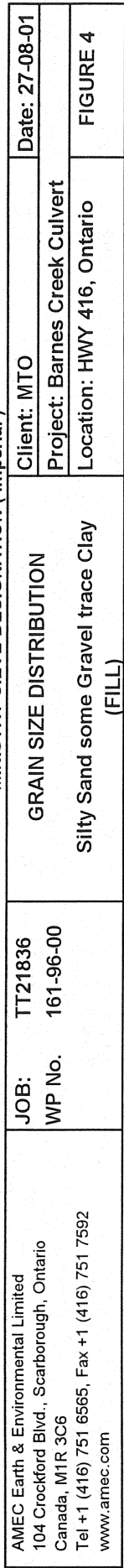


|  |  |   |  |  |                |
|--|--|---|--|--|----------------|
| AMEC Earth & Environmental Limited<br>104 Crockford Blvd., Scarborough, Ontario<br>Canada, M1R 3C6<br>Tel +1 (416) 751 6565, Fax +1 (416) 751 7592<br>www.amec.com | JOB:<br>WP No.<br><br>TT21836<br>161-96-00 | MINISTRY SIEVE DESIGNATION (Imperial)       |  | Client: MTO<br>Project: Barnes Creek Culvert<br>Location: HWY 416, Ontario | Date: 27-08-01 |
|  |  | GRAIN SIZE DISTRIBUTION                     |  |  |                |
|  |  | Sandy Silt, trace Gravel and Clay<br>(FILL) |  |  |                |

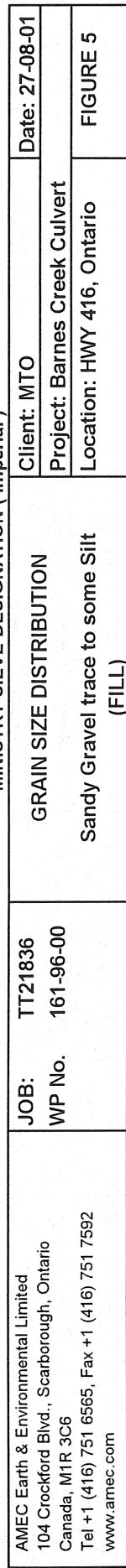
# UNIFIED SOIL CLASSIFICATION SYSTEM



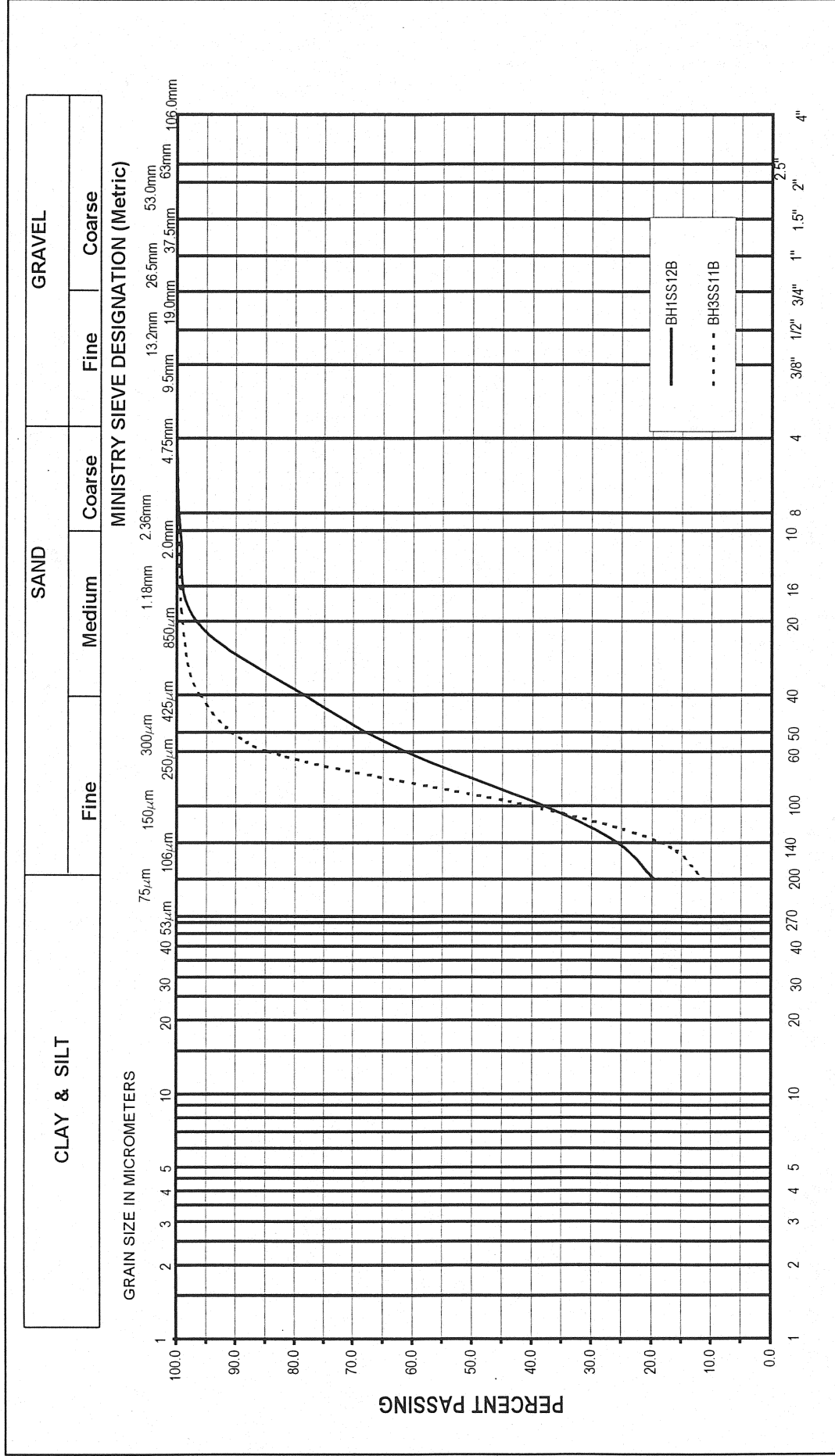
**amec**



**amec**

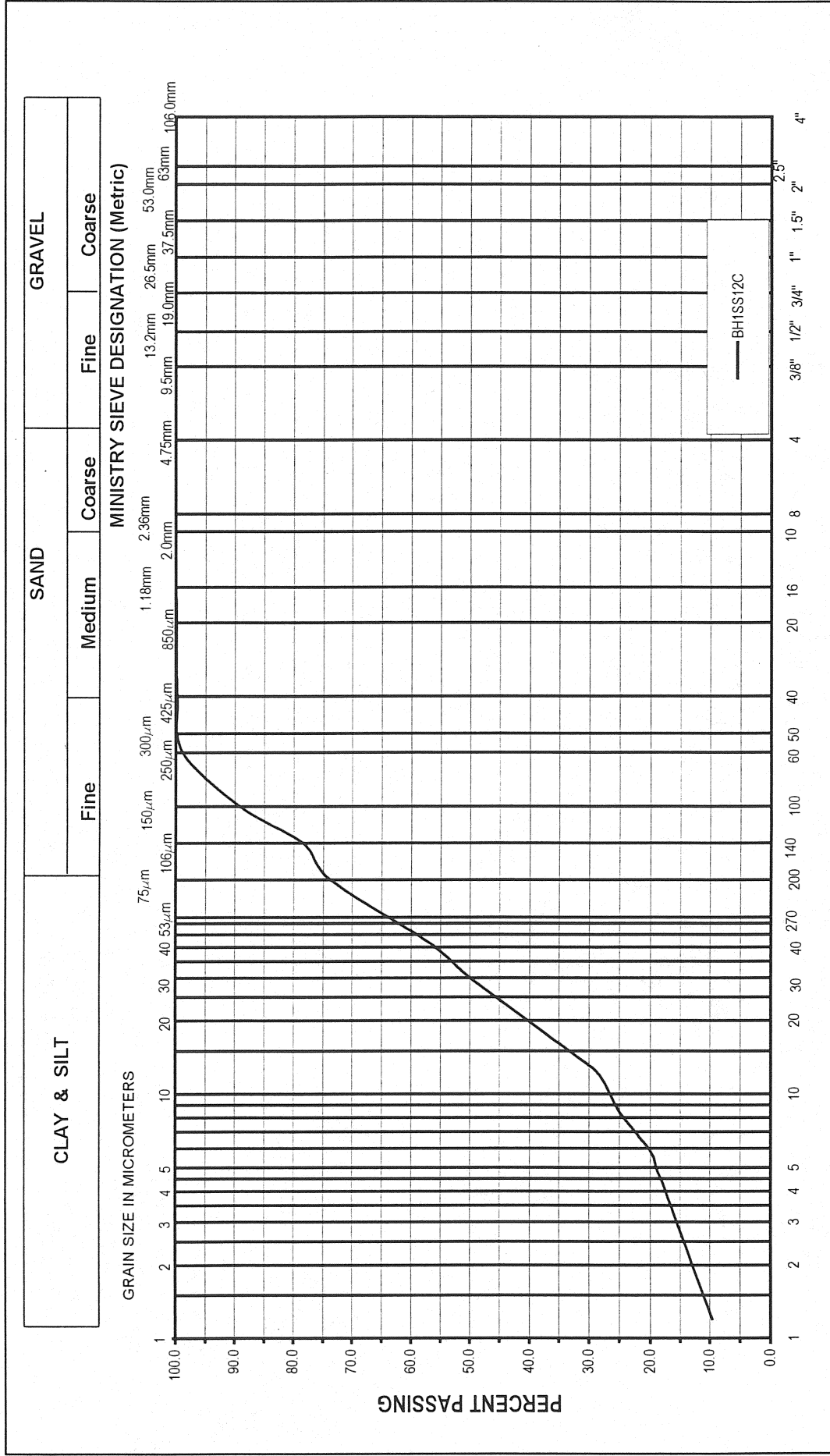


# UNIFIED SOIL CLASSIFICATION SYSTEM



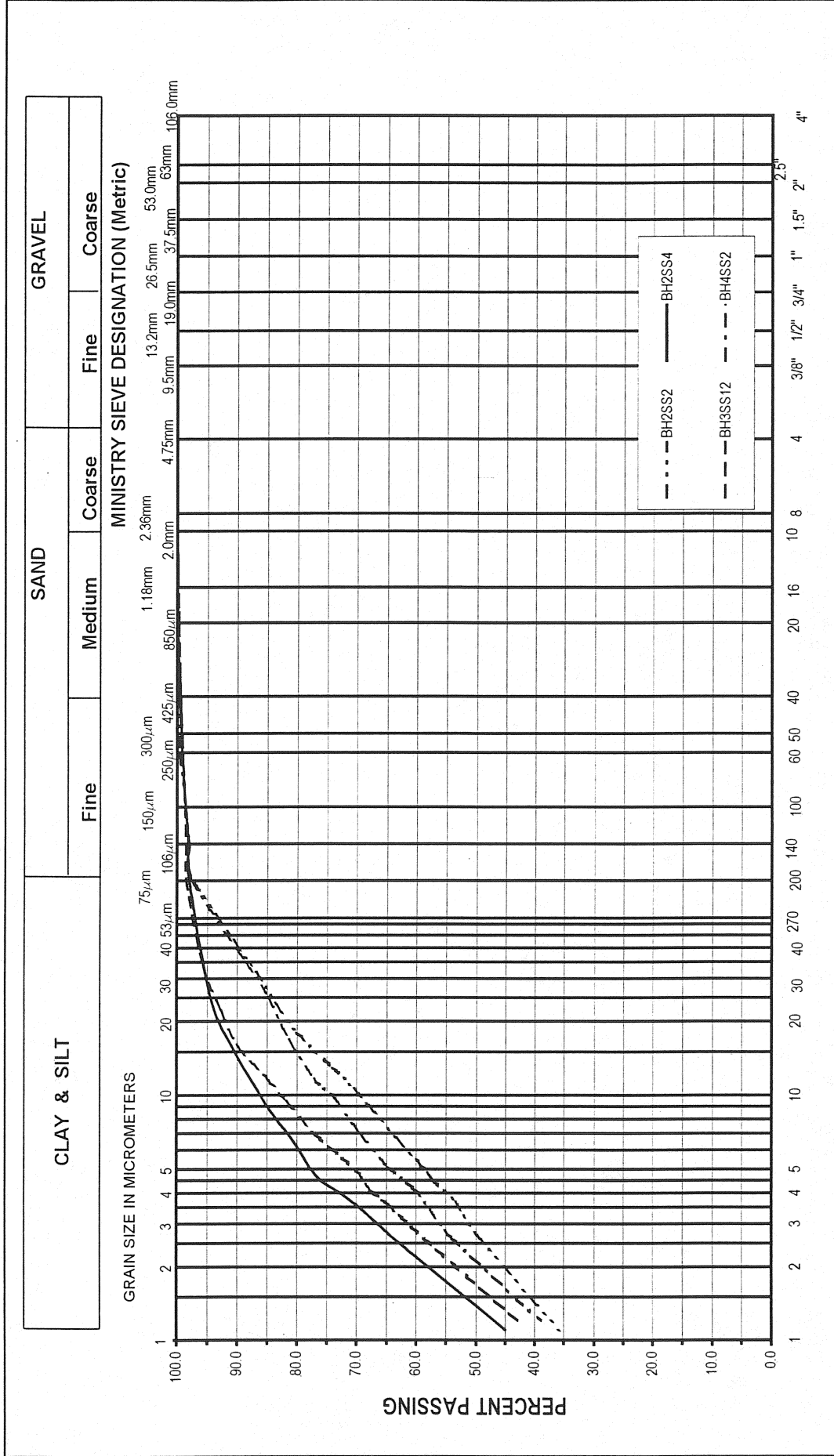
|   |  |  |  |
|---|--|--|--|
| <div>AMEC Earth &amp; Environmental Limited</div> <div>104 Crockford Blvd., Scarborough, Ontario</div> <div>Canada, M1R 3C6</div> <div>Tel +1 (416) 751 6565, Fax +1 (416) 751 7592</div> <div>www.amec.com</div> | <div>JOB:</div> <div>TT21836</div>     |  | <div>Client: MTO</div> <div>Date: 27-08-01</div> |
|   | <div>WP No.</div> <div>161-96-00</div> |  | <div>Project: Barnes Creek Culvert</div>         |
|   | <div>Location: HWY 416, Ontario</div>  |  | <div>FIGURE 6</div>                              |

# UNIFIED SOIL CLASSIFICATION SYSTEM



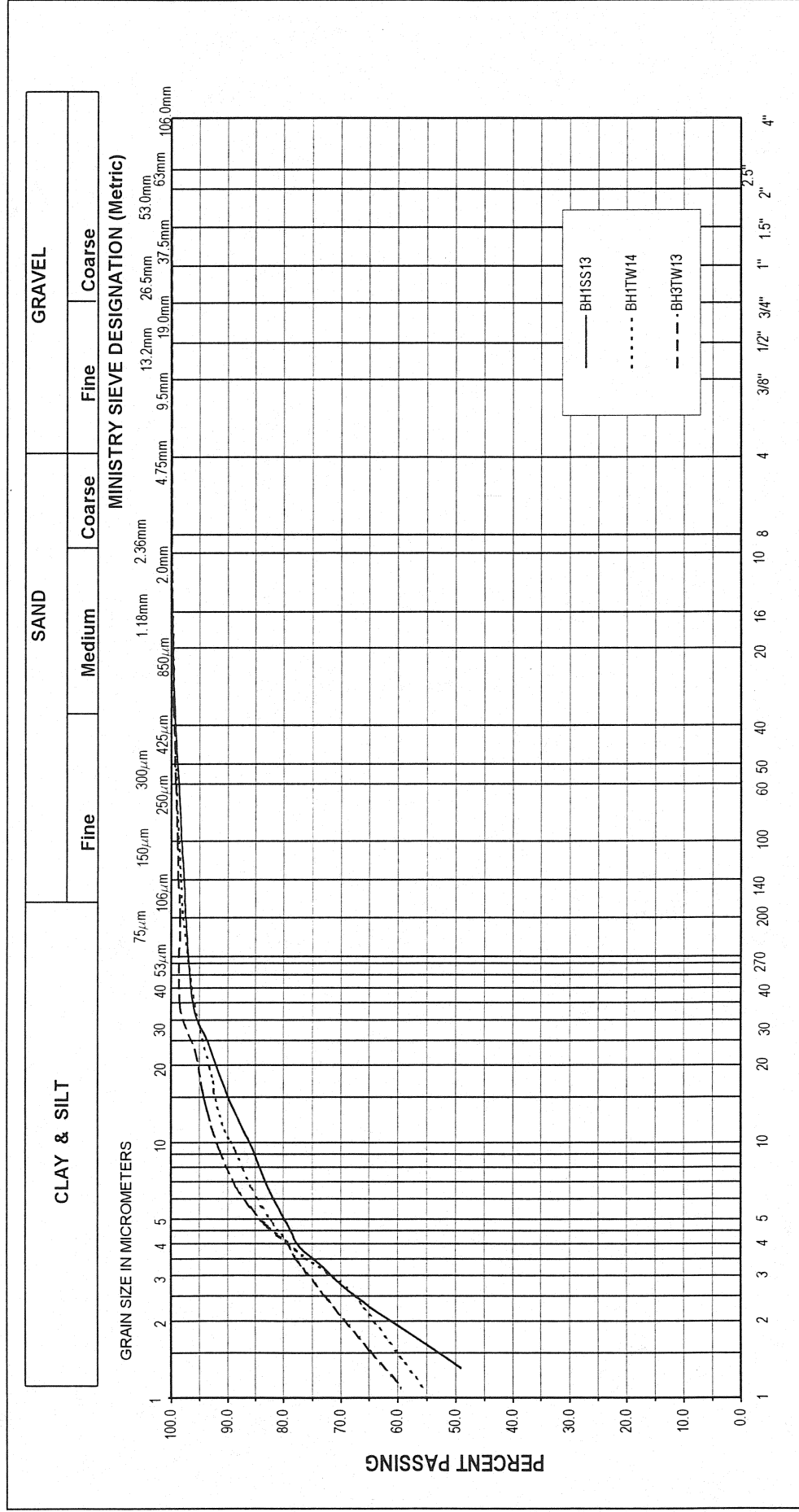
|  |  |                                  |  |   |  |  |  |                |
|--|--|----------------------------------|--|---|--|--|--|----------------|
| AMEC Earth & Environmental Limited<br>104 Crockford Blvd., Scarborough, Ontario<br>Canada, M1R 3C6<br>Tel +1 (416) 751 6565, Fax +1 (416) 751 7592<br>www.amec.com |  | JOB: TT21836<br>WP No. 161-96-00 |  | MINISTRY SIEVE DESIGNATION ( Imperial ) |  | Client: MTO<br>Project: Barnes Creek Culvert<br>Location: HWY 416, Ontario |  | Date: 27-08-01 |
| GRAIN SIZE DISTRIBUTION  |  | Silt with Sand trace Clay        |  | FIGURE 7                                |  |  |  |                |

# UNIFIED SOIL CLASSIFICATION SYSTEM

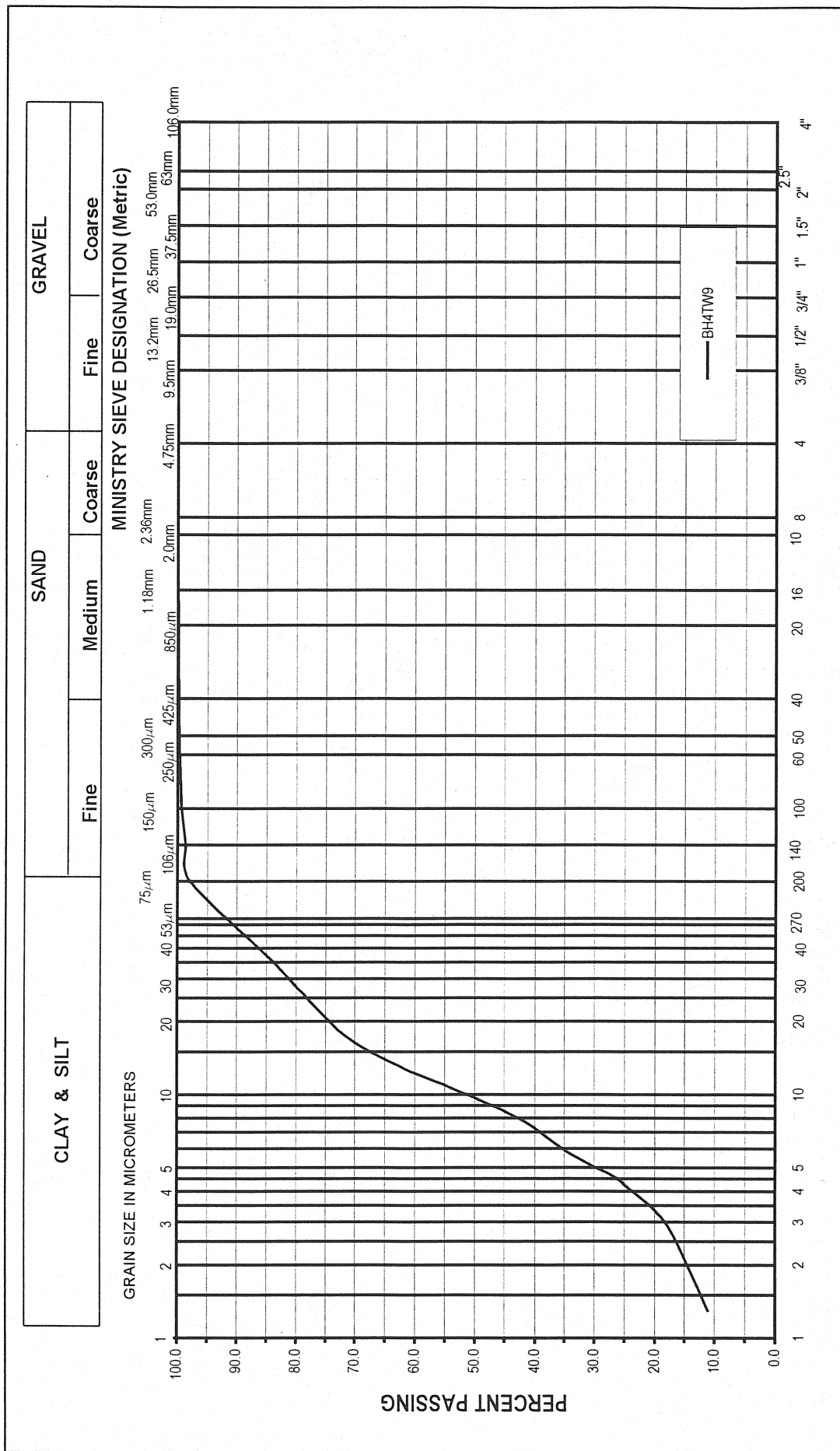


|  |                                       |  |                      |  |  |                |
|--|---------------------------------------|--|----------------------|--|--|----------------|
| AMEC Earth & Environmental Limited<br>104 Crockford Blvd., Scarborough, Ontario<br>Canada, M1R 3C6<br>Tel +1 (416) 751 6565, Fax +1 (416) 751 7592<br>www.amec.com | JOB:<br>WP No.                        |  | TT21836<br>161-96-00 |  | Client: MTO<br>Project: Barnes Creek Culvert<br>Location: HWY 416, Ontario | Date: 27-08-01 |
|  | GRAIN SIZE DISTRIBUTION               |  |                      |  |  |                |
|  | SILTY CLAY                            |  |                      |  |  |                |
|  | MINISTRY SIEVE DESIGNATION (Imperial) |  |                      |  |  |                |
| FIGURE 8   |                                       |  |                      |  |  |                |

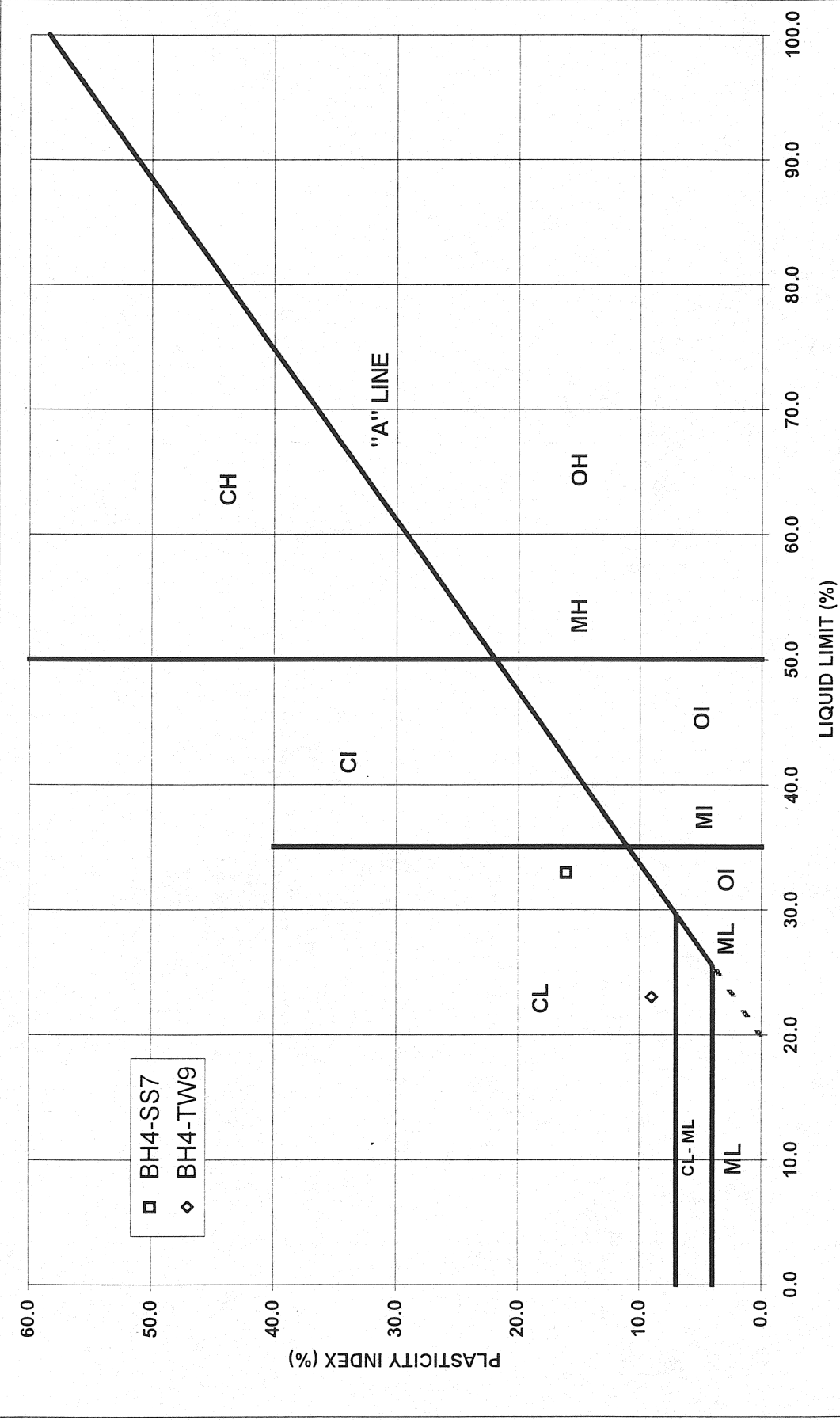
# UNIFIED SOIL CLASSIFICATION SYSTEM



# UNIFIED SOIL CLASSIFICATION SYSTEM



| MINISTRY SIEVE DESIGNATION ( Imperial )  |                |                            |                               |
|--|----------------|----------------------------|-------------------------------|
| AMEC Earth & Environmental Limited<br>104 Crockford Blvd., Scarborough, Ontario<br>Canada, M1R 3C6<br>Tel +1 (416) 751 6565, Fax +1 (416) 751 7592<br>www.amec.com | JOB:           | TT21836                    | GRAIN SIZE DISTRIBUTION       |
|  | WP No.         | 161-96-00                  |                               |
|  | CLAYEY SILT    |                            |                               |
|  | Date: 27-08-01 |                            |                               |
|  |                | Client: MTO                | Project: Barnes Creek Culvert |
|  |                | Location: HWY 416, Ontario |                               |
|  |                | FIGURE 10                  |                               |



104 Crockford Blvd.  
Scarborough, Ontario  
Canada, M1R 3C6  
Tel +1 (416) 751-6565

PLASTICITY CHART

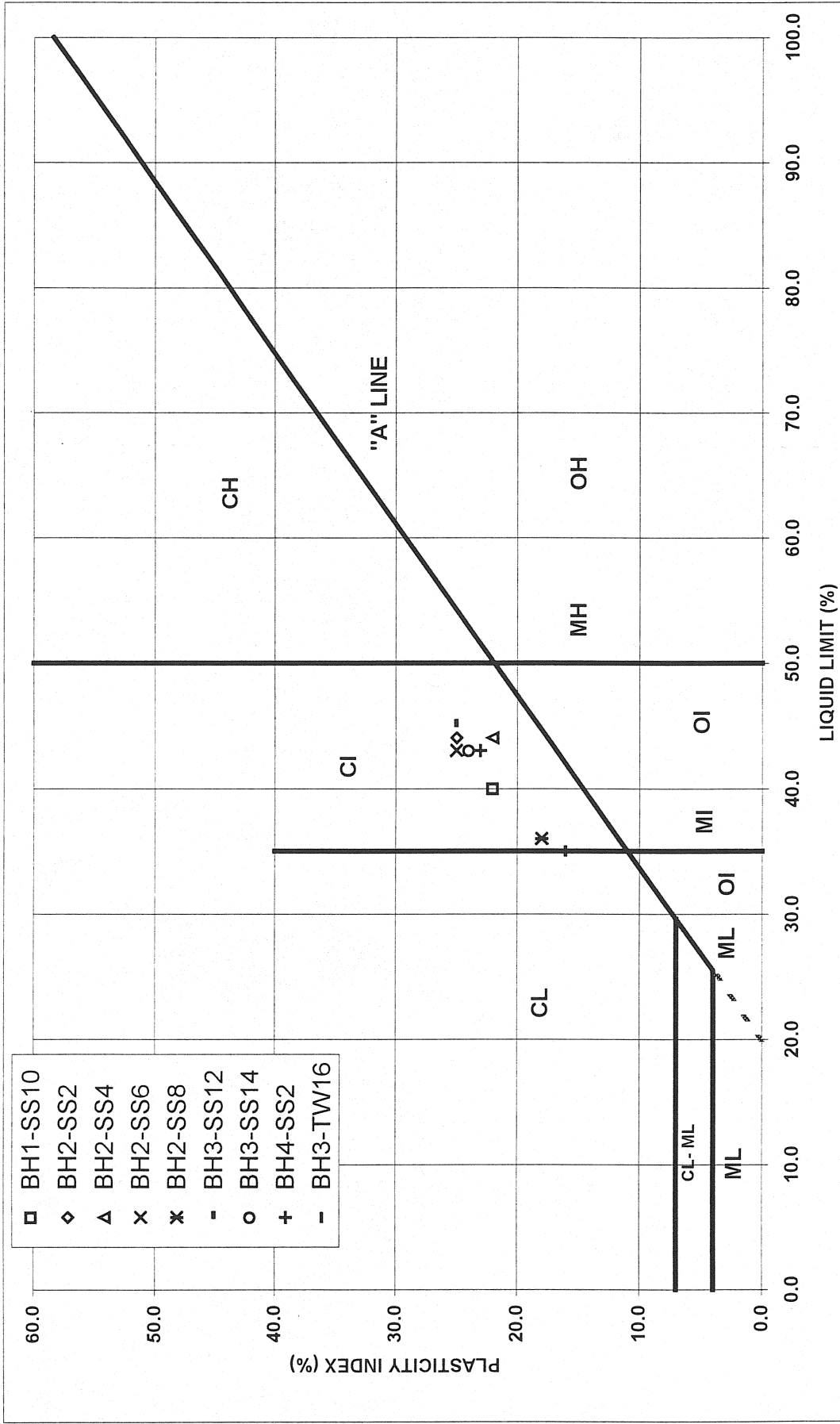
SILTY CLAY (CL)

Job: TT 21836 WP No. 161-96-00 Figure: 11

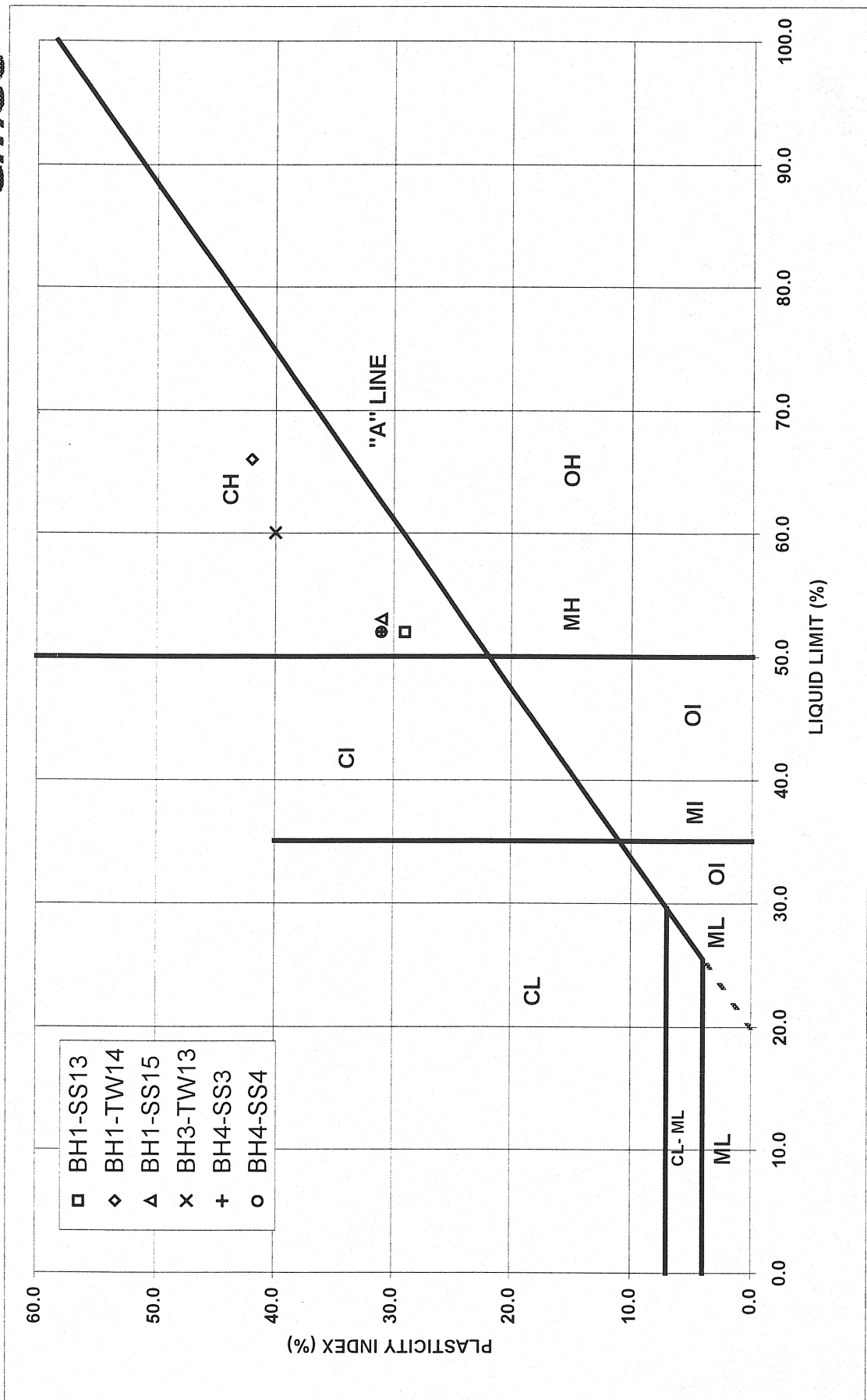
Project: Barnes Creek Culvert

Location: HWY 416

Date: 5 September, 2001



|   |                  |  |                               |                  |            |
|---|------------------|--|-------------------------------|------------------|------------|
| 104 Crockford Blvd.<br>Scarborough, Ontario<br>Canada, M1R 3C6<br>Tel +1 (416) 751-6565 | PLASTICITY CHART |  | Job: TT 21836                 | WP No. 161-96-00 | Figure: 12 |
|   | SILTY CLAY (CI)  |  | Project: Barnes Creek Culvert |                  |            |
|   |                  |  | Location: HWY 416             |                  |            |
|   |                  |  | Date: 5 September, 2001       |                  |            |



|   |                  |  |                               |                  |            |
|---|------------------|--|-------------------------------|------------------|------------|
| 104 Crockford Blvd.<br>Scarborough, Ontario<br>Canada, M1R 3C6<br>Tel +1 (416) 751-6565 | PLASTICITY CHART |  | Job: TT 21836                 | WP No. 161-96-00 | Figure: 13 |
|   | CLAY (CH)        |  | Project: Barnes Creek Culvert |                  |            |
|   |                  |  | Location: HWY 416             |                  |            |
|   |                  |  | Date: 5 September, 2001       |                  |            |

|          |                 |           |               |          |             |        |           |
|----------|-----------------|-----------|---------------|----------|-------------|--------|-----------|
| Project: | Highway 416     | Tested By | IR            | Job No.: | TT21836     | WP NO. | 161-96-00 |
| Date:    | August 24, 2001 | BH No.1   | Sample: TW 14 | Depth:   | 42.5'-43.5' |        |           |

### ONE DIMENSIONAL CONSOLIDATION CURVE

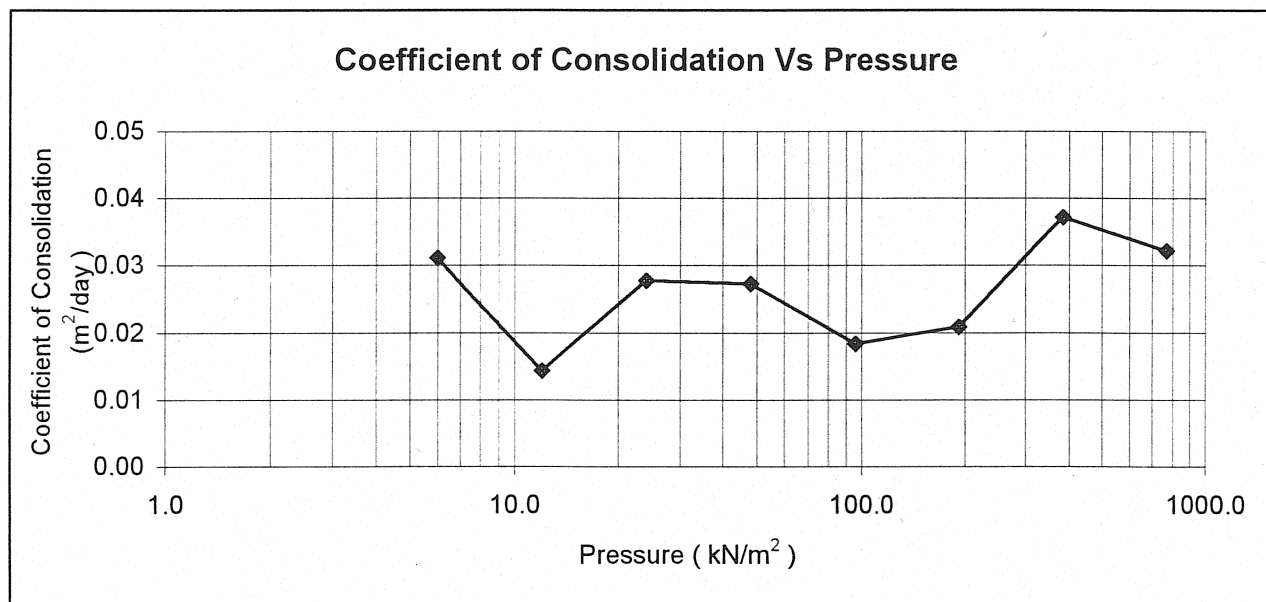
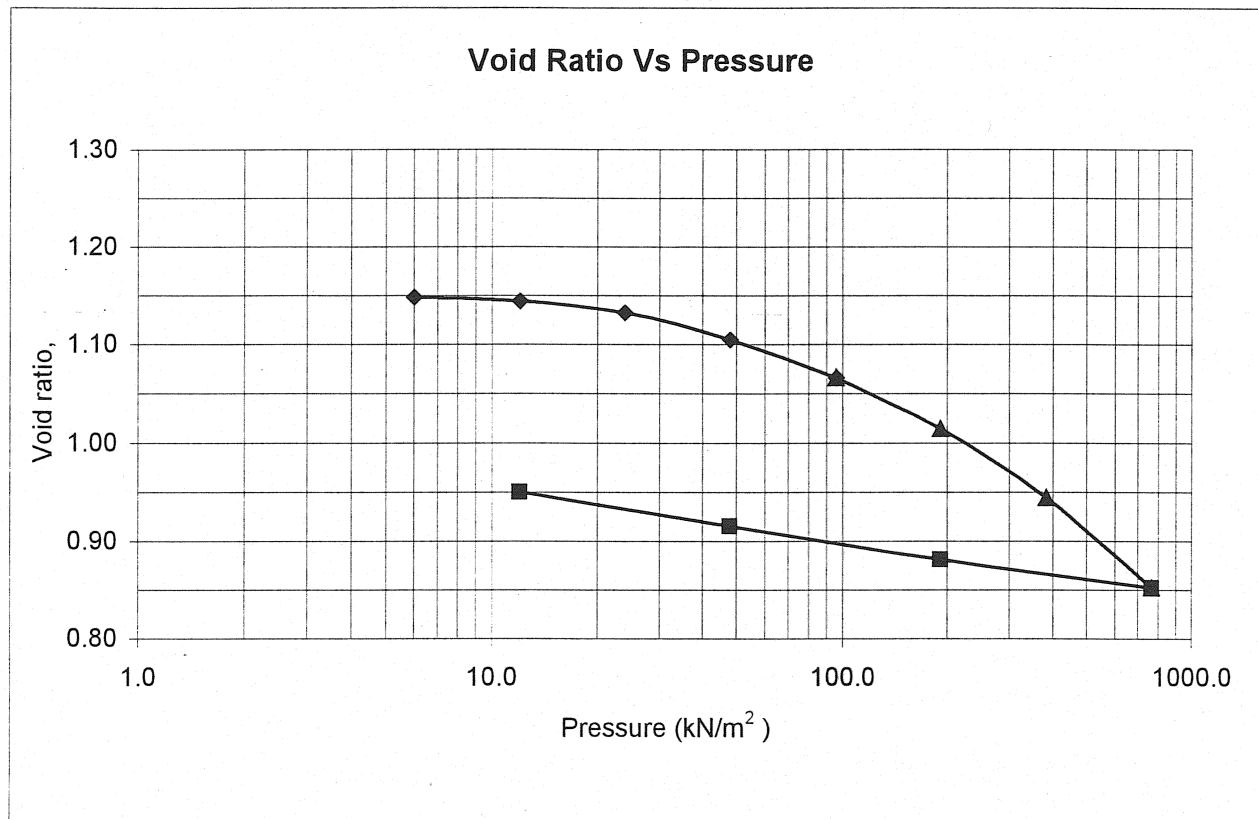


Figure 14

# Strain Energy Method for Preconsolidation Pressure

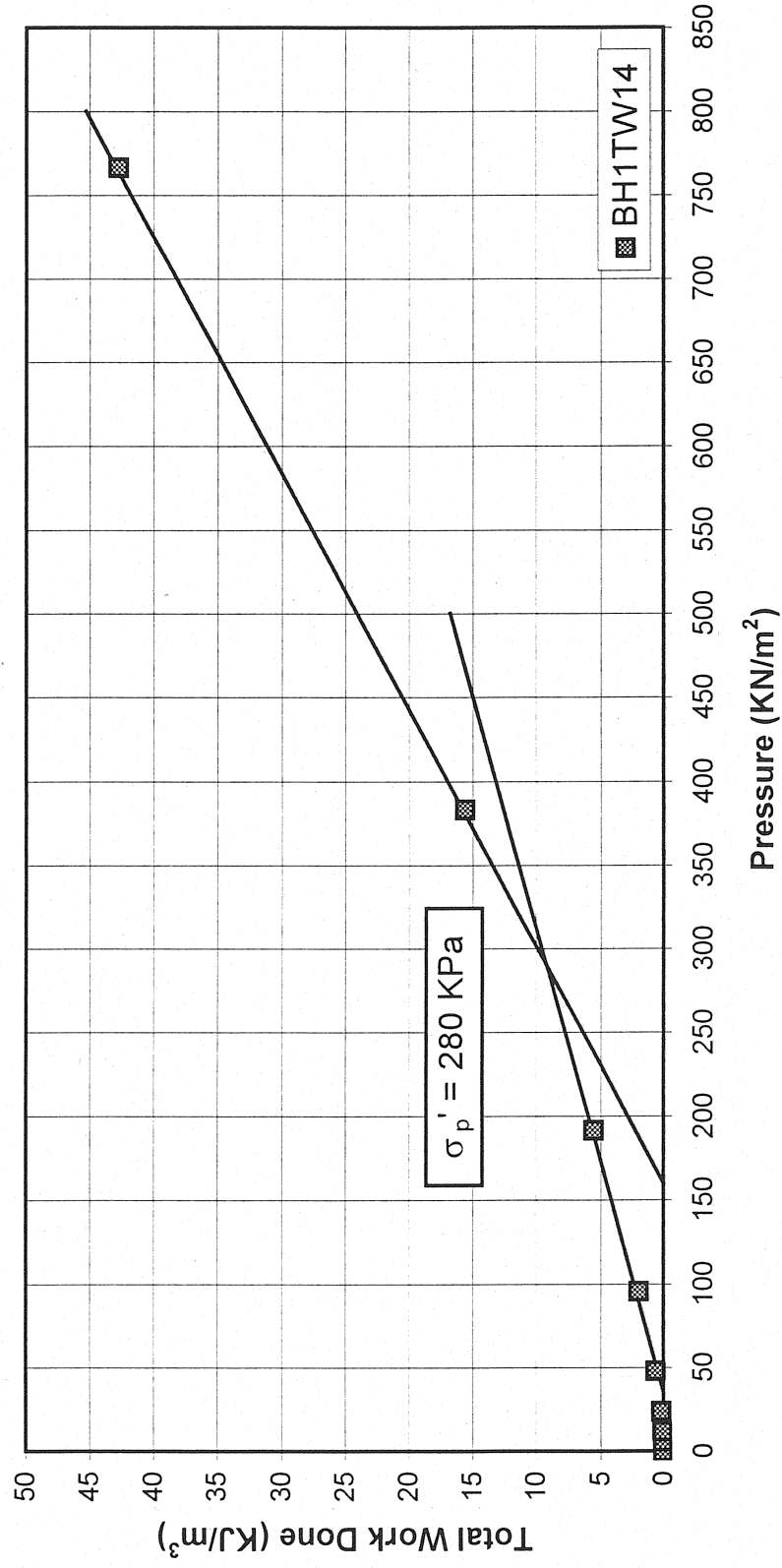


Figure 15

|          |                   |           |               |         |           |        |           |
|----------|-------------------|-----------|---------------|---------|-----------|--------|-----------|
| Project: | Highway 416       | Tested By | IR            | Job No. | TT21836   | WP NO. | 161-96-00 |
| Date:    | September 6, 2001 | BH No. 3  | Sample: TW 13 | Depth:  | 40'-41.5' |        |           |

### ONE DIMENSIONAL CONSOLIDATION CURVE

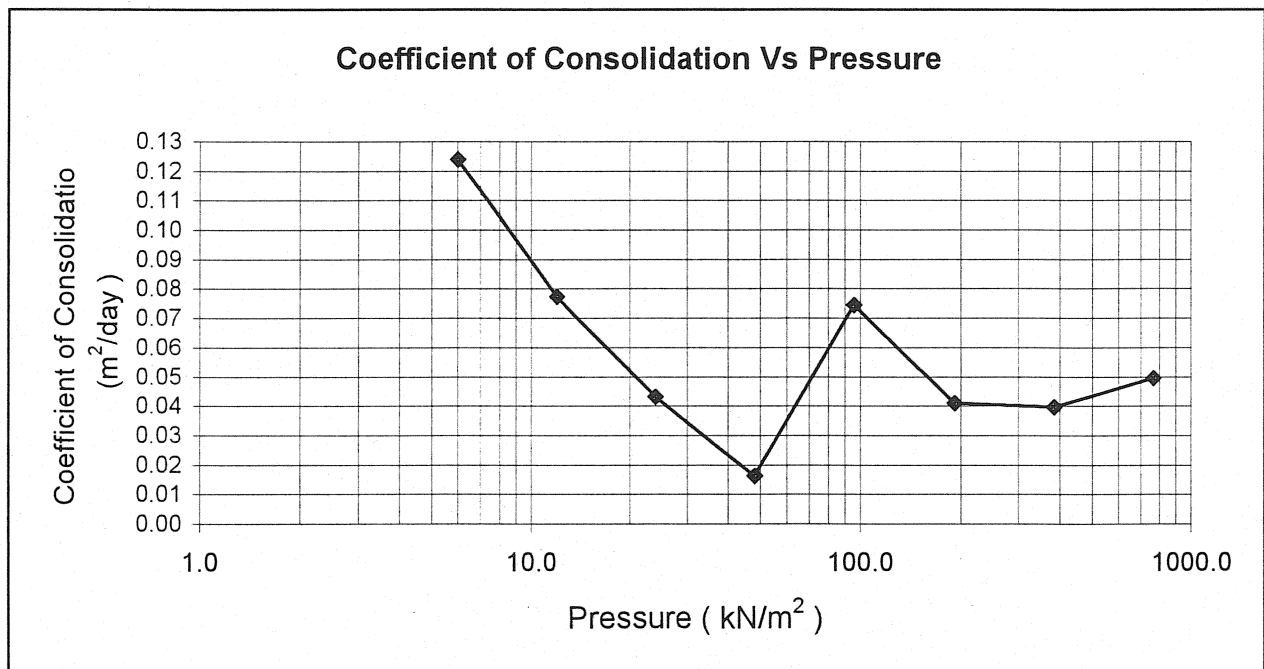
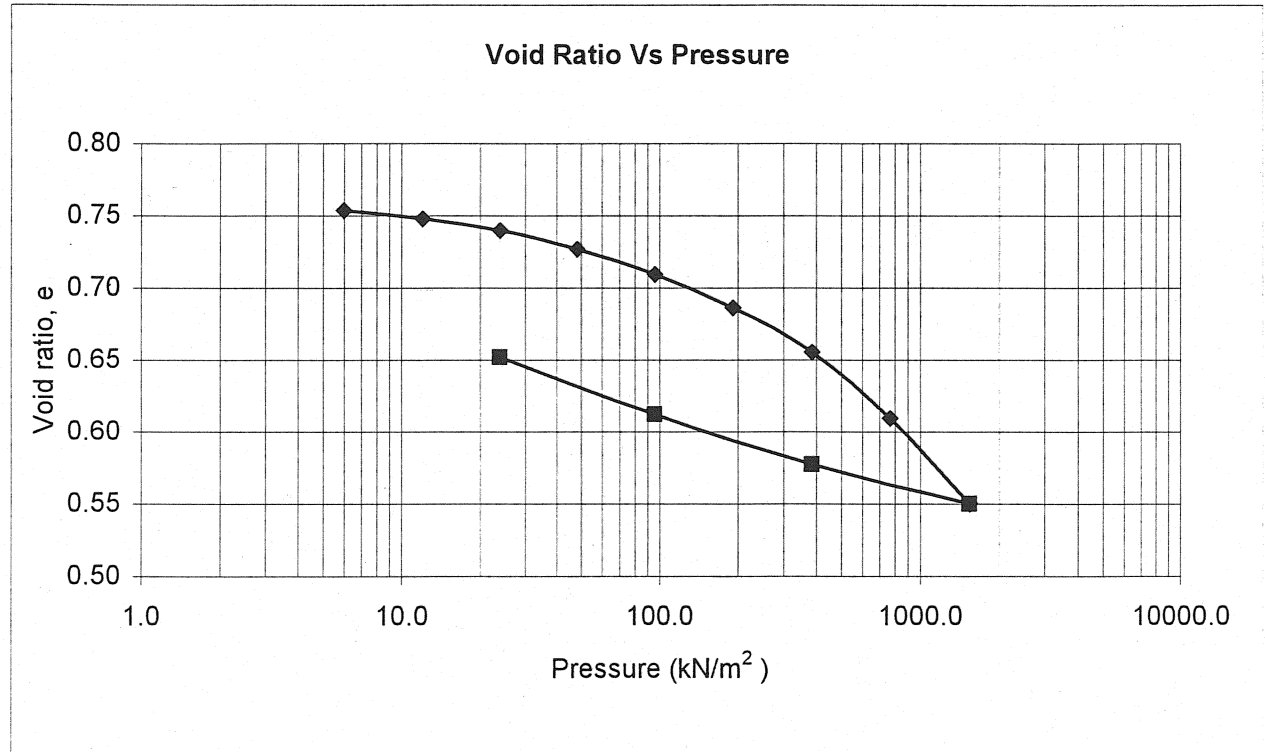


FIGURE 16

# Strain Energy Method for Preconsolidation Pressure

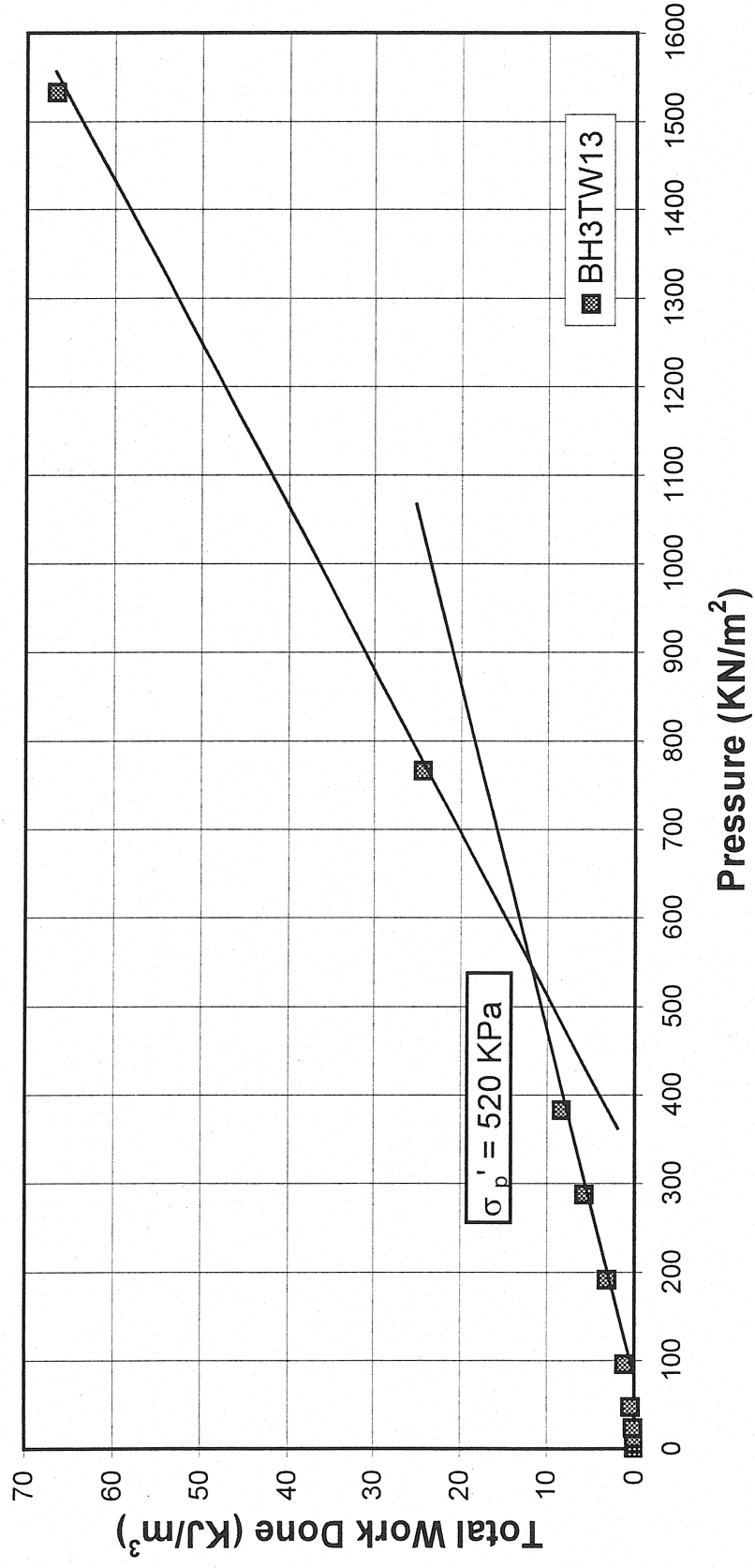


FIGURE 17

Project: Highway 416 Tested By IR Job No. TT21836 WP No. 161-96-00

Date: September 5, 2001 BH No. 4 Sample TW9 Depth 22.5'-24'

### ONE DIMENSIONAL CONSOLIDATION CURVE

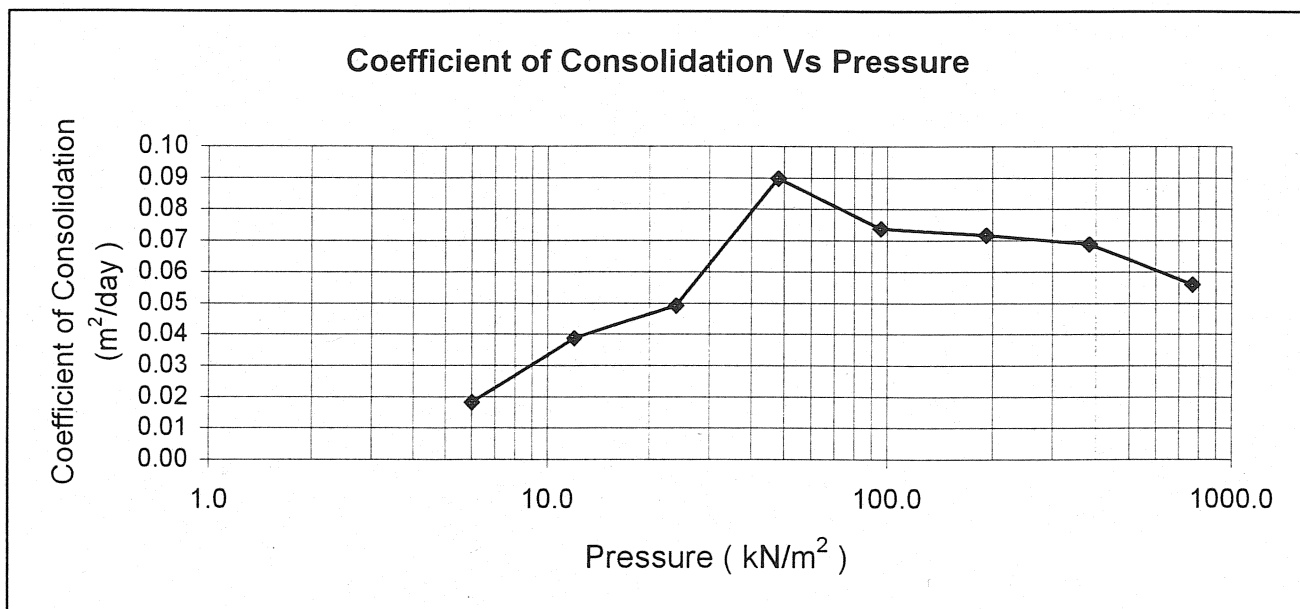
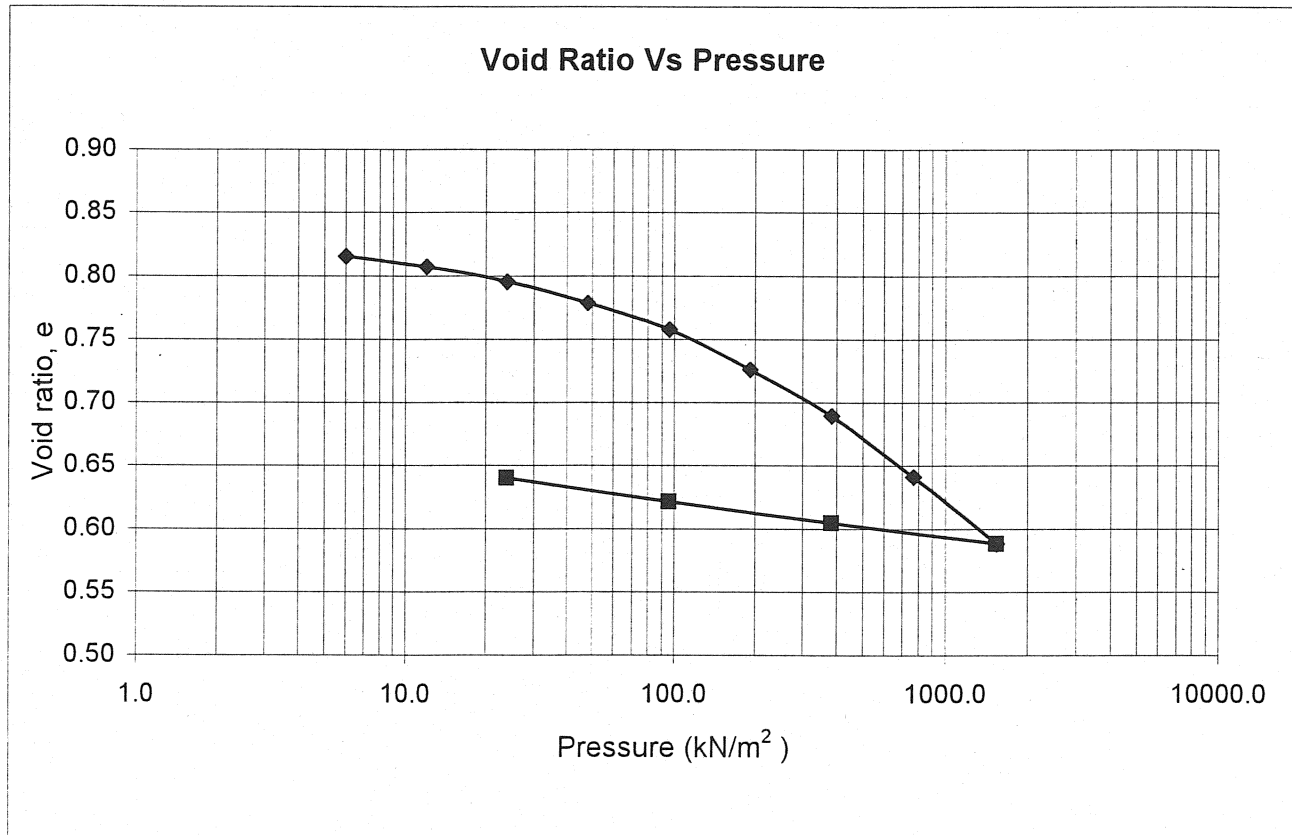


FIGURE 18

# Strain Energy Method for Preconsolidation Pressure

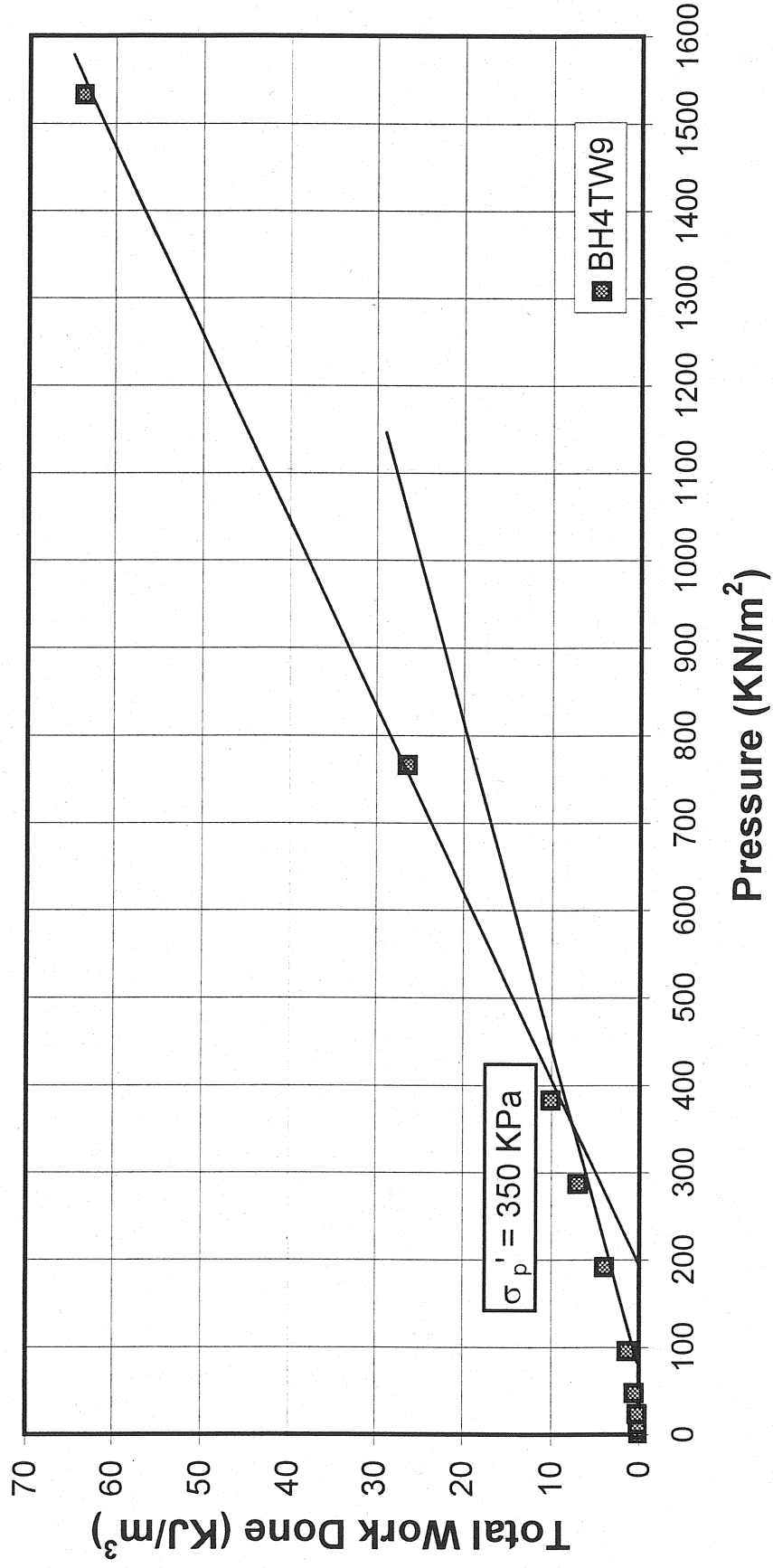


FIGURE 19

**RECORD OF BOREHOLE SHEETS**

## NOTES TO BOREHOLE LOGS

### DRILLING DATA

Method:  
 SolSt Augering - Solid Stem Augering  
 HolSt Augering - Hollow Stem Augering  
 WB - Washed Boring

### SAMPLES

TYPE:  
 SS - Split Spoon  
 AS - Auger Sample  
 TW - Thinwall Open  
 TP - Thinwall Piston  
 WS - Washed Sample  
 BS - Block Sample  
 RC - Rock Core  
 PH - Sample Advanced Hydraulically  
 PM - Sample Advanced Manually

### LABORATORY DATA

PL - Plastic Limit (%)  
 W - Water Content (%)  
 LL - Liquid Limit (%)  
 UNIT WT or  $\gamma$  - Natural Unit Weight (kN/m<sup>3</sup>)  
 UNDR STRNG or  $C_u$  - Undrained Shear Strength (kPa)  
 Field Vane: St-sensitivity  
 pp - Pocket Penetrometer  
 UC - Unconfined Compression  
 UU - Unconsolidated Undrained at Overburden Pressure  
 CU - Consolidated Undrained  
 CD - Consolidated Drained

**Standard Penetration Test, 'N'-values**  
 The Standard Penetration Test (SPT) 'N'-values are the number of blows required to cause a standard 51 millimetre o.d. split barrel sample to penetrate 0.3 metres into undisturbed ground in a borehole when driven by a hammer with a mass of 63.5 kilograms falling freely a distance of 0.76 metres. For penetrations of less than 0.3 metres, N-values are indicated as the number of blows for the penetration achieved (e.g. 50/25: 50 blows for 25 centimetre penetration).

**Dynamic Cone Penetration Test:**  
 Continuous penetration of a conical steel point (51 millimetre o.d. 60° cone angle) driven by 475 J impact energy on a size drill rods. The resistance to cone penetration is measured as the number of blows for each 0.3 metres advance of the conical point into the undisturbed ground.

Soils are described by their composition and consistency or compactness.

**CONSISTENCY:** Cohesive soils are described on the basis of their undrained shear strength ( $C_u$ ) or 'N'-values as follows:

| $C_u$ (kPa)          | 0 - 12    | 12 - 25 | 25 - 50 | 50 - 100 | 100 - 200  | > 200 |
|----------------------|-----------|---------|---------|----------|------------|-------|
|                      | VERY SOFT | SOFT    | FIRM    | STIFF    | VERY STIFF | HARD  |
| N (blows/0.3 metres) | 0 - 2     | 2 - 4   | 4 - 8   | 8 - 15   | 15 - 30    | > 30  |

**COMPACTNESS:** Cohesionless soils are described on the basis of compactness as indicated by 'N'-values as follows:

| N (blows/0.3 metres) | 0 - 4      | 4 - 10 | 10 - 30 | 30 - 50 | > 50       |
|----------------------|------------|--------|---------|---------|------------|
|                      | VERY LOOSE | LOOSE  | COMPACT | DENSE   | VERY DENSE |

Rocks are described by their composition and structural features and/or strength.

**RECOVERY:** Sum of all recovered rock core pieces from a coring run expressed as a percent of the total length of the coring run.

### ROCK QUALITY

**DESIGNATION (RQD):** Sum of those intact core pieces, 100 millimetres in length expressed as a percent of the length of the coring run. Classification of a rock based on the RQD value as follows:

| RQD (%) | 0 - 25    | 25 - 50 | 50 - 75 | 75 - 90 | 90 - 100  |
|---------|-----------|---------|---------|---------|-----------|
|         | VERY POOR | POOR    | FAIR    | GOOD    | EXCELLENT |

### JOINTING AND BEDDING:

| SPACING  | 50 millimetres | 50 - 300 millimetres | 0.3 - 1.0 millimetres | 1.0 - 3.0 millimetres | > 3.0 millimetres |
|----------|----------------|----------------------|-----------------------|-----------------------|-------------------|
| JOINTING | VERY CLOSE     | CLOSE                | MOD. CLOSE            | WIDE                  | VERY WIDE         |
| BEDDING  | VERY THIN      | THIN                 | MEDIUM                | THICK                 | VERY THICK        |

# RECORD OF BOREHOLE No 1

1 OF 2

W.P. 161-96-00 LOCATION N 4985035 E 374368 ORIGINATED BY PPM  
 DIST 9 HWY 416 BOREHOLE TYPE Hollow Stem Augering COMPILED BY PPM  
 DATUM Geodetic DATE 26 July 2001 - 26 July 2001 CHECKED BY RM  
 PROJECT Proposed Barnes Creek Culvert, Highway 416, South of Kemptville JOB NO. TT21836

| SOIL PROFILE         |  |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | DEPTH<br>m | ELEVATION SCALE<br>m | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT |    |    |    |     | PLASTIC LIMIT<br>w <sub>p</sub> | NATURAL<br>MOISTURE<br>CONTENT<br>w | LIQUID LIMIT<br>w <sub>L</sub> | UNIT<br>WEIGHT<br>γ | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%) |                   |  |  |
|----------------------|--|------------|---------|------|------------|----------------------------|------------|----------------------|---|----|----|----|-----|---------------------------------|-------------------------------------|--------------------------------|---------------------|---|-------------------|--|--|
| ELEV<br>DEPTH<br>(m) | DESCRIPTION  | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |            |                      | SHEAR STRENGTH kPa                          |    |    |    |     |                                 |                                     |                                |                     |   | WATER CONTENT (%) |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 107.0                |  |            |         |      |            |                            |            |                      | 20  | 40 | 60 | 80 | 100 |                                 |                                     |                                |                     |   |                   |  |  |
| 0.0                  | brown-grey<br>Sand and Gravel FILL<br>damp                                       |            | 1       | SS   | 30         |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 105.9                |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 1.1                  | grey<br>Sandy Silt FILL<br>some gravel, trace rootlets<br>moist                  |            | 2       | SS   | 9          |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      | -----<br>occasional cobbles  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      | -----<br>damp  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            | 3       | SS   | 40         |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            | 4       | SS   | 63         |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            | 5       | SS   | 50/8       |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  | 6          | SS      | 50   |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      | -----<br>trace clay  |            | 7       | SS   | 50/8       |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      | -----<br>moist   |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  | 8          | SS      | 45   |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
|                      |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 98.0                 |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 9.0                  | grey<br>Silty Sand FILL<br>with gravel, trace clay<br>occasional cobbles<br>damp |            | 9       | SS   | 50/10      |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 97.3                 |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 9.7                  | grey<br>Silty Clay FILL  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |
| 97.0                 |  |            |         |      |            |                            |            |                      |   |    |    |    |     |                                 |                                     |                                |                     |   |                   |  |  |

Continued Next Page

+ 3, X 3: Numbers refer to Sensitivity

○ 3% STRAIN AT FAILURE

# RECORD OF BOREHOLE No 1

2 OF 2

|         |   |          |                             |               |                      |             |     |
|---------|---|----------|-----------------------------|---------------|----------------------|-------------|-----|
| W.P.    | 161-96-00   | LOCATION | N 4985035 E 374368          | 2 OF 2        | ORIGINATED BY        | PPM         |     |
| DIST    | 9   | HWY      | 416                         | BOREHOLE TYPE | Hollow Stem Augering | COMPILED BY | PPM |
| DATUM   | Geodetic  | DATE     | 26 July 2001 - 26 July 2001 | CHECKED BY    | RM                   |             |     |
| PROJECT | Proposed Barnes Creek Culvert, Highway 416, South of Kemptville |          |                             |               | JOB NO.              | TT21836     |     |

| SOIL PROFILE         |             |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | DEPTH<br>m | ELEVATION SCALE<br>m | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT |                            | PLASTIC<br>LIMIT<br>W <sub>p</sub> | NATURAL<br>MOISTURE<br>CONTENT<br>W | LIQUID<br>LIMIT<br>W <sub>L</sub> | UNIT<br>WEIGHT<br>γ<br>kN/m <sup>3</sup> | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%)<br>GR SA SI CL |                   |
|----------------------|-------------|------------|---------|------|------------|----------------------------|------------|----------------------|---|----------------------------|------------------------------------|-------------------------------------|-----------------------------------|--|--|-------------------|
| ELEV<br>DEPTH<br>(m) | DESCRIPTION | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |            |                      | SHEAR STRENGTH kPa                          |                            |                                    |                                     |                                   |  |  | WATER CONTENT (%) |
|                      |             |            |         |      |            |                            |            |                      | ○ UNCONFINED<br>● QUICK TRIAXIAL            | + FIELD VANE<br>× LAB VANE |                                    |                                     |                                   |  |  |                   |

|      |   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|------|---|----|----|----|----|--|--|--|--|--|--|--|--|------|------|---|
| 10.0 | grey<br>Silty Clay FILL<br>trace gravel, trace organics |    | 10 | SS | 15 |  |  |  |  |  |  |  |  | 18.0 |      |   |
| 96.4 | moist   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
| 10.6 | grey<br>Silty Sand FILL<br>with gravel, some clay,      |    | 11 | SS | 57 |  |  |  |  |  |  |  |  |      |      | SS hitting a rock<br>24 34 30 12                            |
| 95.7 | rock fragments  |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
| 11.4 | TOPSOIL   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
| 95.4 |   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
| 95.0 | grey, SAND  |    | 12 | SS | 14 |  |  |  |  |  |  |  |  |      |      | 0 80 (20)   |
| 11.8 | compact, some silt and rootlets, wet                    |    |    |    |    |  |  |  |  |  |  |  |  |      |      | 0 26 61 13  |
| 94.9 | compact, grey, SILT, moist to wet                       |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
| 12.1 | with sand, trace clay seams                             |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      | grey<br>CLAY to SILTY CLAY                              |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      | stiff   | 13 | SS | 15 |    |  |  |  |  |  |  |  |  | 52   | 19.3 | 0 2 37 61   |
|      | trace shell fragments                                   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      | moist   | 14 | TW | -  |    |  |  |  |  |  |  |  |  | 66   | 18.3 | 0 2 34 64   |
|      | very stiff  |    |    |    |    |  |  |  |  |  |  |  |  |      |      | TW14:<br>consolidation test<br>(see fig. 14)                |
|      |   | 15 | SS | 29 |    |  |  |  |  |  |  |  |  |      |      |   |
|      | trace gravel  |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      |   | 16 | SS | 18 |    |  |  |  |  |  |  |  |  |      |      |   |
|      |   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      | stiff   | 17 | SS | 11 |    |  |  |  |  |  |  |  |  |      |      |   |
|      |   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      |   |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      | with silt layers or seams                               |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
|      | wet   | 18 | SS | 1* |    |  |  |  |  |  |  |  |  |      |      | *Probably disturbed due to hydrostatic uplift.              |
| 89.5 | grey, GRAVEL, with silt, wet                            |    |    |    |    |  |  |  |  |  |  |  |  |      |      |   |
| 17.7 | END OF BOREHOLE   |    |    |    |    |  |  |  |  |  |  |  |  |      |      | Groundwater inside hollow stem augers on completion: 16.8m. |
|      | AUGER REFUSAL DUE TO POSSIBLE BEDROCK                   |    |    |    |    |  |  |  |  |  |  |  |  |      |      | Borehole was grouted on completion.                         |

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE

# RECORD OF BOREHOLE No 2



1 OF 1

W.P. 161-96-00 LOCATION N 4985016 E 374343 ORIGINATED BY PPM  
 DIST 9 HWY 416 BOREHOLE TYPE Hollow Stem Augering COMPILED BY PPM  
 DATUM Geodetic DATE 30 July 2001 - 30 July 2001 CHECKED BY RM  
 PROJECT Proposed Barnes Creek Culvert, Highway 416, South of Kempville JOB NO. TT21836

| SOIL PROFILE    |                                       |             | SAMPLES |      |            | GROUND WATER CONDITIONS | DEPTH<br>m | ELEVATION SCALE<br>m | DYNAMIC CONE PENETRATION RESISTANCE PLOT |  | PLASTIC LIMIT<br>w <sub>p</sub> | NATURAL MOISTURE CONTENT<br>w | LIQUID LIMIT<br>w <sub>L</sub> | UNIT WEIGHT<br>γ | REMARKS & GRAIN SIZE DISTRIBUTION (%)  |
|-----------------|---------------------------------------|-------------|---------|------|------------|-------------------------|------------|----------------------|--|--|---------------------------------|-------------------------------|--------------------------------|------------------|--|
| ELEV. DEPTH (m) | DESCRIPTION                           | STRAT. PLOT | NUMBER  | TYPE | "N" VALUES |                         |            |                      | SHEAR STRENGTH kPa                       |  |                                 |                               |                                |                  |  |
| 95.7            | 0.1m TOPSOIL                          |             |         |      |            |                         |            |                      | ○ UNCONFINED + FIELD VANE                |  |                                 |                               |                                |                  |  |
| 95.6            | light brown Sand FILL                 |             | 1       | SS   | 2          |                         |            |                      | ● QUICK TRIAXIAL × LAB VANE              |  |                                 |                               |                                |                  |  |
| 95.1            | trace silt seams, damp                |             |         |      |            |                         |            |                      | 20 40 60 80 100                          |  |                                 |                               |                                |                  |  |
| 95.1            | grey SILTY CLAY                       |             |         |      |            |                         |            |                      |  |  |                                 |                               |                                |                  |  |
| 0.6             | firm                                  |             | 2       | SS   | 3          |                         | 1          |                      |  |  |                                 |                               |                                |                  | 0 78 (22)  |
|                 | stiff                                 |             | 3       | SS   | 11         |                         |            |                      |  |  |                                 |                               |                                |                  | 0 3 51 46  |
|                 | moist                                 |             | 4       | SS   | 11         |                         | 2          |                      | 6%                                       |  |                                 |                               |                                | 19.6             | 0 2 40 58  |
|                 | very stiff                            |             | 5       | SS   | 18         |                         | 3          |                      |  |  |                                 |                               |                                |                  |  |
|                 | trace gravel                          |             | 6       | SS   | 25         |                         |            |                      |  |  |                                 |                               |                                |                  |  |
|                 | hard                                  |             | 7       | SS   | 38         |                         | 4          |                      |  |  |                                 |                               |                                |                  |  |
|                 | stiff                                 |             | 8       | SS   | 8          |                         |            |                      |  |  |                                 |                               |                                | 21.0             |  |
|                 |                                       |             | 9       | SS   | 7          |                         | 5          |                      |  |  |                                 |                               |                                |                  |  |
|                 |                                       |             | 10      | SS   | 6          |                         | 6          |                      |  |  |                                 |                               |                                |                  |  |
|                 | with silt seams                       |             | 11      | SS   | 6          |                         |            |                      |  |  |                                 |                               |                                |                  |  |
|                 | moist to wet                          |             | 12      | SS   | 6          |                         | 7          |                      |  |  |                                 |                               |                                |                  |  |
| 88.1            | grey, GRAVEL, with silt, wet          |             | 13      | SS   | 53         |                         |            |                      |  |  |                                 |                               |                                |                  |  |
| 7.8             | END OF BOREHOLE                       |             |         |      |            |                         |            |                      |  |  |                                 |                               |                                |                  |  |
|                 | SPOON REFUSAL DUE TO POSSIBLE BEDROCK |             |         |      |            |                         |            |                      |  |  |                                 |                               |                                |                  | Groundwater in open bore on completion: 1.5m<br>Groundwater in piezometer: 1.2m, Aug. 2, 2001. |

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

# RECORD OF BOREHOLE No 3



1 OF 2

W.P. 161-96-00 LOCATION N 4985069 E 374405 ORIGINATED BY PPM  
 DIST 9 HWY 416 BOREHOLE TYPE Hollow Stem Augering COMPILED BY PPM  
 DATUM Geodetic DATE 27 July 2001 - 27 July 2001 CHECKED BY RM  
 PROJECT Proposed Barnes Creek Culvert, Highway 416, South of Kemptville JOB NO. TT21836

| SOIL PROFILE         |   |            | SAMPLES |      |            | GROUND WATER<br>CONDITIONS | DEPTH<br>m | ELEVATION SCALE<br>m | DYNAMIC CONE PENETRATION<br>RESISTANCE PLOT |              | PLASTIC<br>LIMIT<br>w <sub>p</sub> | NATURAL<br>MOISTURE<br>CONTENT<br>w | LIQUID<br>LIMIT<br>w <sub>L</sub> | UNIT<br>WEIGHT<br>γ | REMARKS<br>&<br>GRAIN SIZE<br>DISTRIBUTION<br>(%) |                   |
|----------------------|---|------------|---------|------|------------|----------------------------|------------|----------------------|---|--------------|------------------------------------|-------------------------------------|-----------------------------------|---------------------|---|-------------------|
| ELEV<br>DEPTH<br>(m) | DESCRIPTION   | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                            |            |                      | SHEAR STRENGTH kPa                          |              |                                    |                                     |                                   |                     |   | WATER CONTENT (%) |
|                      |   |            |         |      |            |                            |            |                      | ○ UNCONFINED                                | + FIELD VANE |                                    |                                     |                                   |                     |   |                   |
|                      |   |            |         |      |            |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
| 106.4<br>0.0         | brown-grey<br>Sand and Gravel FILL<br>damp  |            | 1       | SS   | 53         |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
| 105.3<br>1.1         | brown<br>Sand FILL<br>trace gravel and silt<br>damp                                 |            | 2       | SS   | 49         |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
| 103.2<br>3.2         | grey, Clayey Silt FILL, moist   |            | 3       | SS   | 43         |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
| 103.0<br>3.4         | trace gravel  |            |         |      |            |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
|                      | brown<br>Sand FILL<br>trace gravel<br>damp  |            | 4       | SS   | 95         |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
|                      | trace wood particles  |            | 5       | SS   | 68         |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
|                      |   |            | 6       | SS   | 80         |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |
|                      | with gravel<br>occasional cobbles   |            | 7       | SS   | 60/23      |                            |            |                      |   |              |                                    |                                     |                                   |                     | 1 89 (10)   |                   |
| 98.2<br>8.2          | grey-brown<br>Sandy Gravel FILL<br>trace to some silt<br>occasional cobbles<br>damp |            | 8       | SS   | 28         |                            |            |                      |   |              |                                    |                                     |                                   |                     | 48 35 (18)  |                   |
|                      |   |            | 9       | SS   | 64         |                            |            |                      |   |              |                                    |                                     |                                   |                     | 65 27 (8)   |                   |
|                      |   | 10         | SS      | 50/8 |            |                            |            |                      |   |              |                                    |                                     |                                   |                     |   |                   |

Continued Next Page

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

# RECORD OF BOREHOLE No 3

2 OF 2

|         |   |          |                             |               |                      |
|---------|---|----------|-----------------------------|---------------|----------------------|
| W.P.    | 161-96-00   | LOCATION | N 4985069 E 374405          | ORIGINATED BY | PPM                  |
| DIST    | 9   | HWY      | 416                         | BOREHOLE TYPE | Hollow Stem Augering |
| DATUM   | Geodetic  | DATE     | 27 July 2001 - 27 July 2001 | COMPILED BY   | PPM                  |
| PROJECT | Proposed Barnes Creek Culvert, Highway 416, South of Kemptville |          |                             |               | CHECKED BY           |
|         |   |          |                             |               | RM                   |
|         |   |          |                             | JOB NO.       | TT21836              |

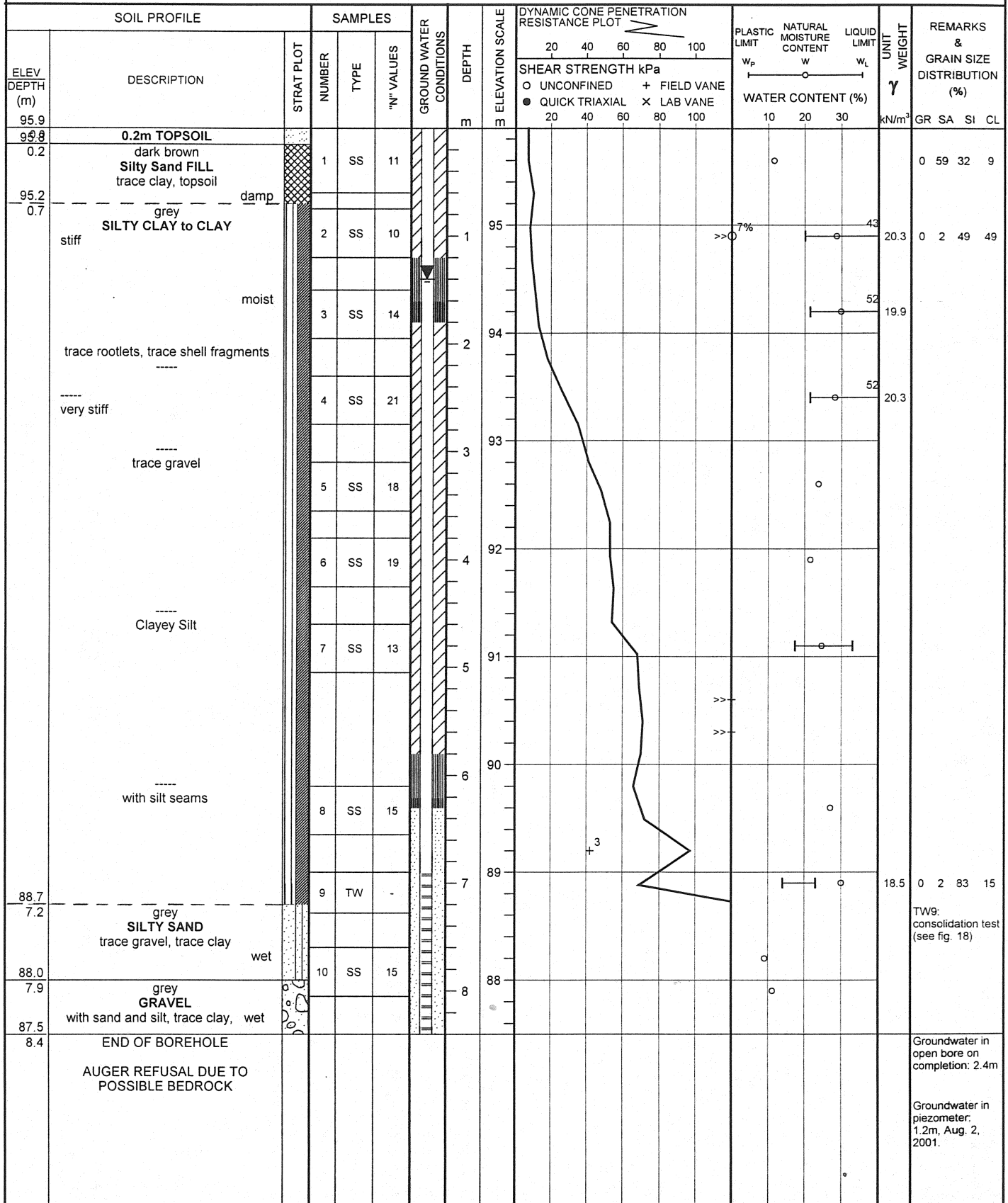
| SOIL PROFILE         |   |            | SAMPLES |      |            | GROUND WATER CONDITIONS | DEPTH<br>m | ELEVATION<br>SCALE<br>m | DYNAMIC CONE PENETRATION RESISTANCE PLOT |                 | PLASTIC LIMIT<br>W <sub>p</sub> | NATURAL MOISTURE CONTENT<br>W | LIQUID LIMIT<br>W <sub>L</sub> | UNIT WEIGHT<br>γ<br>kN/m <sup>3</sup> | REMARKS & GRAIN SIZE DISTRIBUTION (%) |
|----------------------|---|------------|---------|------|------------|-------------------------|------------|-------------------------|--|-----------------|---------------------------------|-------------------------------|--------------------------------|---------------------------------------|---------------------------------------|
| ELEV<br>DEPTH<br>(m) | DESCRIPTION   | STRAT PLOT | NUMBER  | TYPE | "N" VALUES |                         |            |                         | SHEAR STRENGTH kPa                       |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            |         |      |            |                         |            |                         | 20 40 60 80 100                          | 20 40 60 80 100 |                                 |                               |                                |                                       |                                       |
|                      |   |            |         |      |            |                         |            |                         | ○ UNCONFINED + FIELD VANE                |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            |         |      |            |                         |            |                         | ● QUICK TRIAXIAL x LAB VANE              |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
| 95.8                 | grey-brown<br>Sandy Gravel FILL<br>occasional cobbles |            |         |      |            |                         |            | 96                      |  |                 |                                 |                               |                                |                                       |                                       |
| 10.6                 | dark brown<br>Sandy TOPSOIL                           |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
| 95.4                 |   |            | 11      | SS   | 38         |                         | 11         |                         |  |                 |                                 |                               | 21.2                           | 0 89 (11)                             |                                       |
| 11.0                 | grey, SAND, wet<br>trace silt                         |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
| 95.1                 | grey<br>SILTY CLAY to CLAY                            |            |         |      |            |                         |            | 95                      |  |                 |                                 |                               |                                |                                       |                                       |
| 11.3                 | moist   |            | 12      | SS   | 15         |                         |            |                         |  |                 |                                 |                               | 20.2                           | 0 2 44 54                             |                                       |
|                      | trace gravel, trace rootlets                          |            |         |      |            |                         | 12         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | very stiff  |            | 13      | TW   | -          |                         |            | 94                      |  |                 |                                 |                               | 18.6                           | 0 2 29 69                             |                                       |
|                      |   |            |         |      |            |                         | 13         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            |         |      |            |                         |            | 93                      |  |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            | 14      | SS   | 22         |                         | 14         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | moist   |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | trace gravel  |            | 15      | SS   | 15         |                         | 15         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            |         |      |            |                         | 15         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            | 16      | TW   | -          |                         | 16         |                         |  |                 |                                 |                               | 20.5                           |                                       |                                       |
|                      |   |            |         |      |            |                         | 16         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            | 17      | SS   | 16         |                         | 17         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | stiff   |            |         |      |            |                         | 17         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            | 18      | SS   | 11         |                         | 18         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      |   |            |         |      |            |                         | 18         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | with silt and clay seams                              |            |         |      |            |                         | 18         |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | very stiff  |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | wet   |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
| 87.7                 |   |            | 19      | SS   | 19         |                         |            | 88                      |  |                 |                                 |                               |                                |                                       |                                       |
| 18.7                 | grey<br>GRAVEL, with silt, wet                        |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
| 87.3                 |   |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
| 19.1                 | END OF BOREHOLE                                       |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |
|                      | AUGER REFUSAL DUE TO POSSIBLE BEDROCK                 |            |         |      |            |                         |            |                         |  |                 |                                 |                               |                                |                                       |                                       |

# RECORD OF BOREHOLE No 4



1 OF 1

W.P. 161-96-00 LOCATION N 4985084 E 374433 ORIGINATED BY PPM  
 DIST 9 HWY 416 BOREHOLE TYPE Hollow Stem Augering COMPILED BY PPM  
 DATUM Geodetic DATE 30 July 2001 - 30 July 2001 CHECKED BY RM  
 PROJECT Proposed Barnes Creek Culvert, Highway 416, South of Kemptville JOB NO. TT21836



+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

**DRAWING**

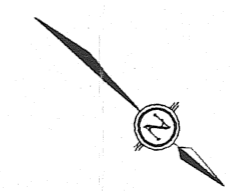


W.P. No. 161-96-00

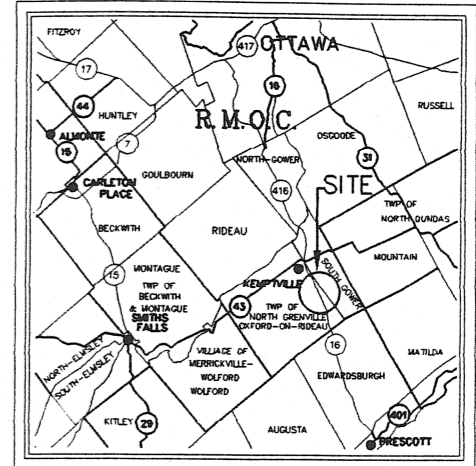
BORE HOLE LOCATIONS & SOIL STRATA  
STATION 20+190 (NBL)  
BARNES CREEK CULVERT

SHEET

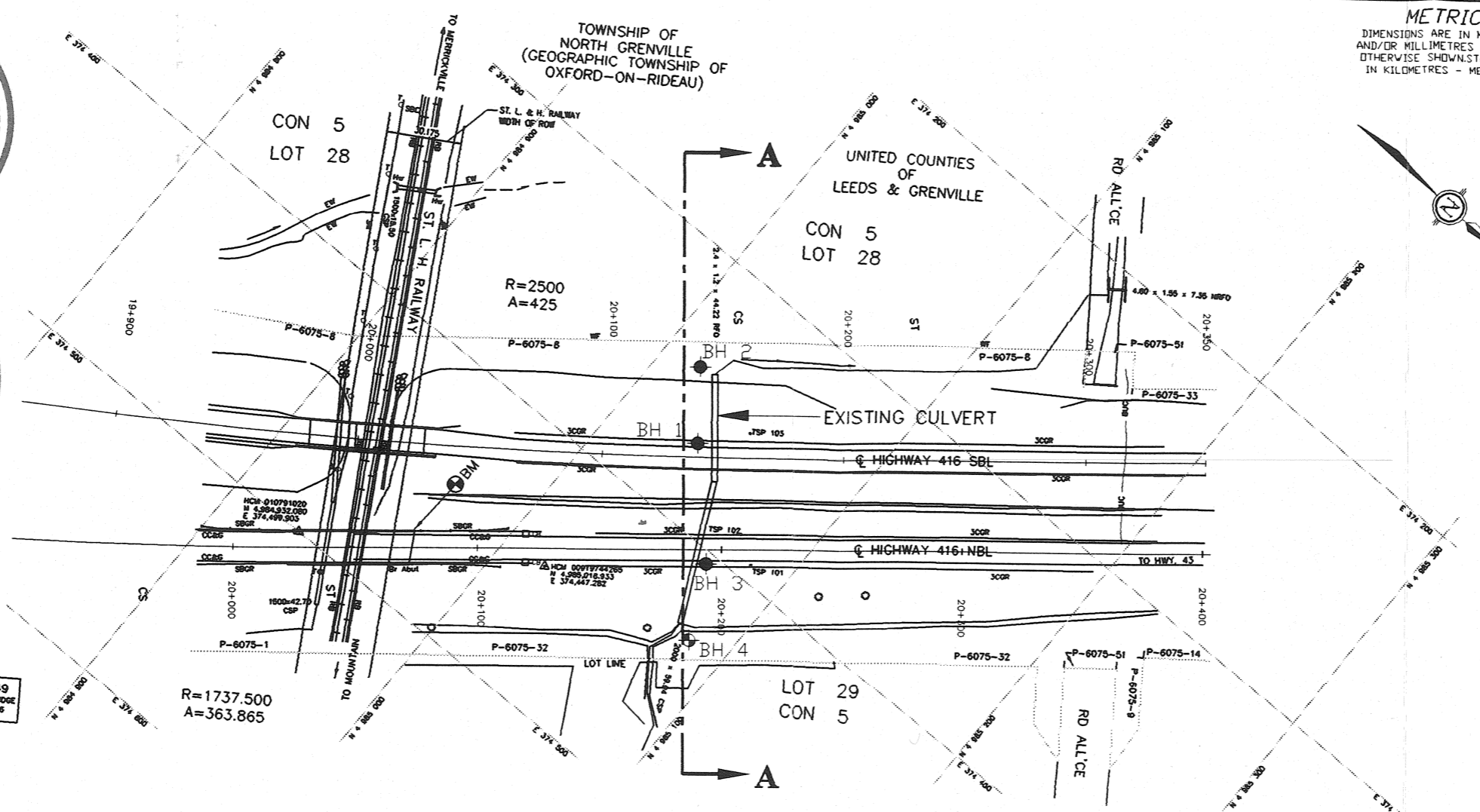
METRIC  
DIMENSIONS ARE IN METRES  
AND/OR MILLIMETRES UNLESS  
OTHERWISE SHOWN. STATIONS  
IN KILOMETRES - METRES.



AMEC Earth & Environmental Limited

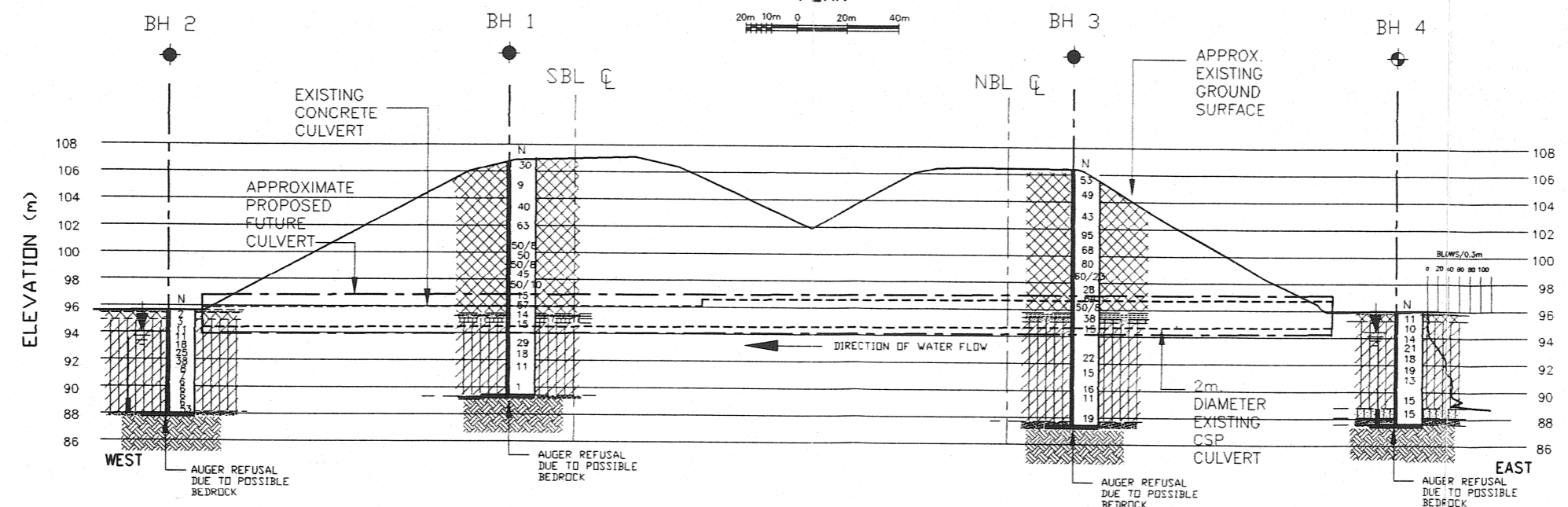


KEY PLAN

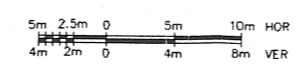


SOIL STRATIGRAPHY LEGEND

- FILL SAND with GRAVEL Silty Clay & Sandy Silt
- TOP SOIL
- SILT
- SAND
- SILTY CLAY to CLAY
- GRAVEL Sandy Gravel to Gravelly Sand
- SILTY SAND
- BEDROCK Dolostone



SECTION A-A AT STATION 20+190 (NBL)



- LEGEND
- Bore Hole
  - Bore Hole & Cone
  - 'N' Blows/0.3m (Std Pen Test, 475 J/blow)
  - CONE Blows/0.3m (60° Cone, 475 J/blow)
  - WL at time of Investigation
  - WL in Piezometer (AUGUST 02, 2001)
  - Piezometer
  - End of Borehole

| No                                  | ELEVATION | CO-ORDINATES |         |
|-------------------------------------|-----------|--------------|---------|
|                                     |           | NORTHING     | EASTING |
| BH 1                                | 107.0     | 4 985 035    | 374 368 |
| BH 2                                | 95.7      | 4 985 016    | 374 343 |
| BH 3                                | 106.4     | 4 985 069    | 374 405 |
| BH 4                                | 95.9      | 4 985 084    | 374 433 |
| EXISTING CULVERT INVERT AT EAST END | 94.7      |              |         |
| EXISTING CULVERT INVERT AT WEST END | 94.4      |              |         |

-NOTE-

The boundaries between soil strata have been established only at Bore Hole locations. Between Bore Holes the boundaries are assumed from geological evidence.

NOTE: The complete foundation investigation and design report for this project and other related documents may be examined at the Engineering Materials Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with the conditions of Section 2.01 of OPS GenCond.

| REV | DATE | BY | DESCRIPTION |
|-----|------|----|-------------|
|-----|------|----|-------------|

|                                      |        |
|--------------------------------------|--------|
| HWY 416, BARNES CREEK CULVERT        | DIST 9 |
| SUBM'D RM CHECKED KSH DATE SEP. 2001 | SITE   |
| DRAWN NS CHECKED                     | DWG 1  |

FILE: K:\Geo-Transport\Projects\112136\Drawings